Environment and
Climate Change Canada

Environnement et
Changement climatique Canada

Canada

# Toward user-relevant seasonal forecasts of Arctic sea ice: The FRAMS project

**Bill Merryfield**

**Canadian Centre for Climate Modelling and Analysis (CCCma)**

APPLICATE GA, 28-30 Jan 2019

# Forecasting Regional Arctic Sea Ice from a Month to Seasons

FRAMS

MEOPAR

**Funded by Canada’s Marine Environmental Prediction and Response network (MEOPAR)**
**Endorsed by Year of Polar Prediction (YOPP)**

YOPP
YEAR OF POLAR PREDICTION

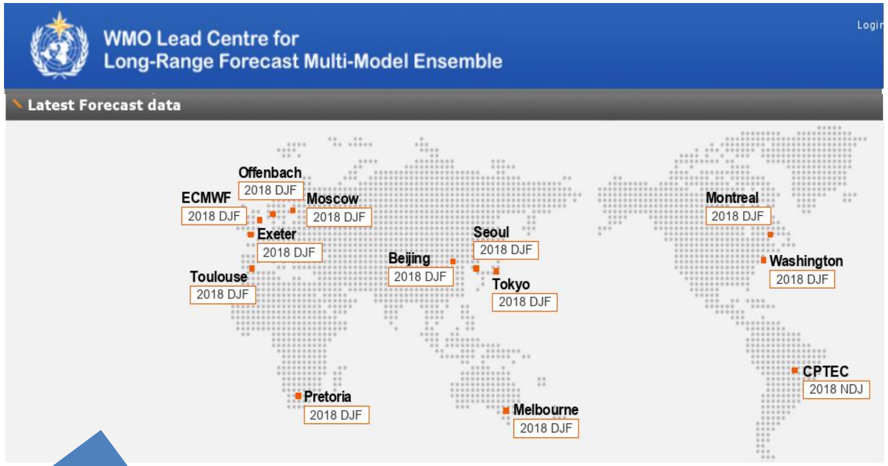
- **Overall objective**: develop multi-model *user-relevant* forecasts of Arctic Sea ice on time scales from a month to seasons

- Seasonal sea ice forecasting capabilities for **ECCC**, including **Canadian Ice Service**

- Multi-model sea ice forecasting capabilities for the **WMO ArcRCC**, inputs for **PARCOF**s

# WMO seasonal forecasting framework

## Lead Centre

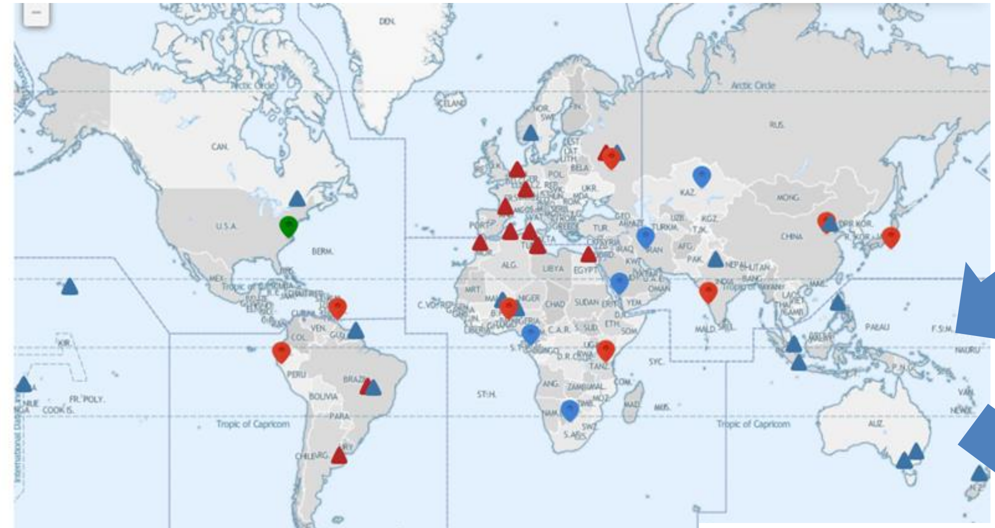


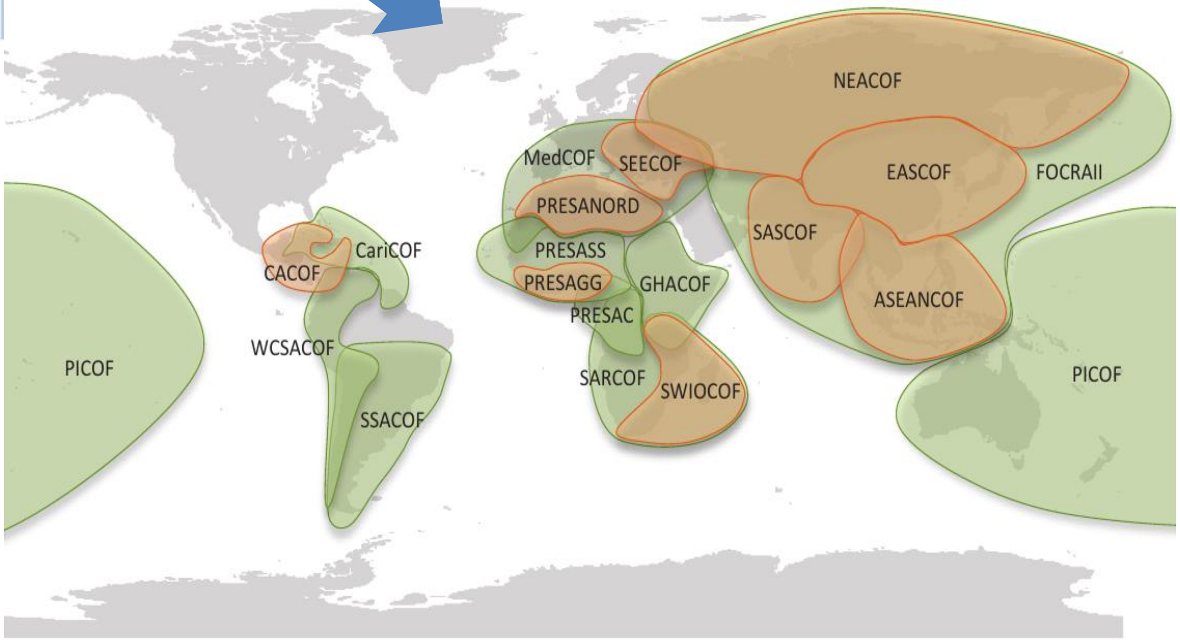
WMO Lead Centre for Long-Range Forecast Multi-Model Ensemble

Latest Forecast data

Offenbach 2018 DJF
ECMWF 2018 DJF
Moscow 2018 DJF
Exeter 2018 DJF
Toulouse 2018 DJF
Beijing 2018 DJF
Seoul 2018 DJF
Tokyo 2018 DJF
Pretoria 2018 DJF
Melbourne 2018 DJF
Montreal 2018 DJF
Washington 2018 DJF
CPTEC 2018 NDJ

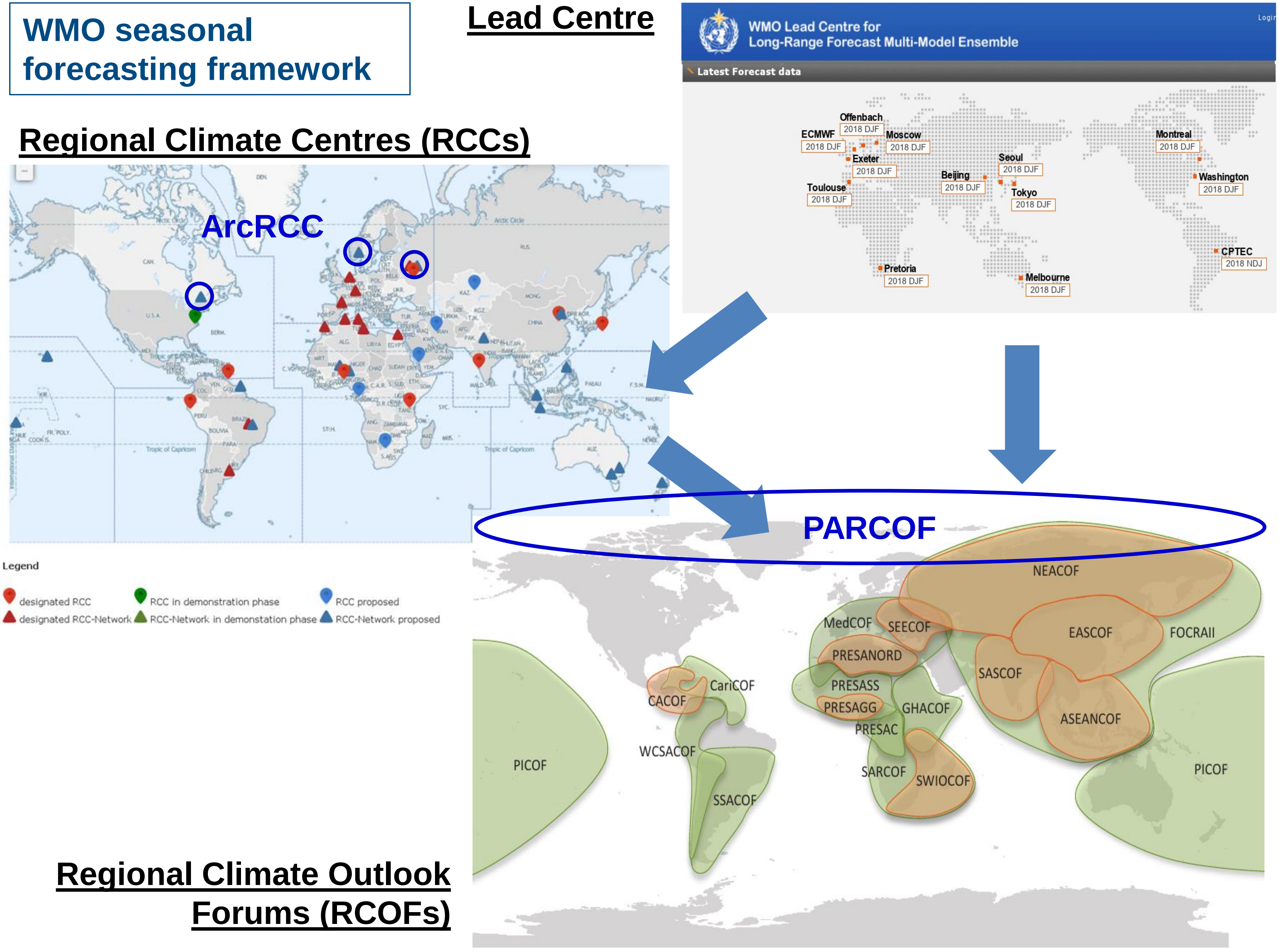
## Regional Climate Centres (RCCs)





## Regional Climate Outlook Forums (RCOFs)

# WMO seasonal forecasting framework



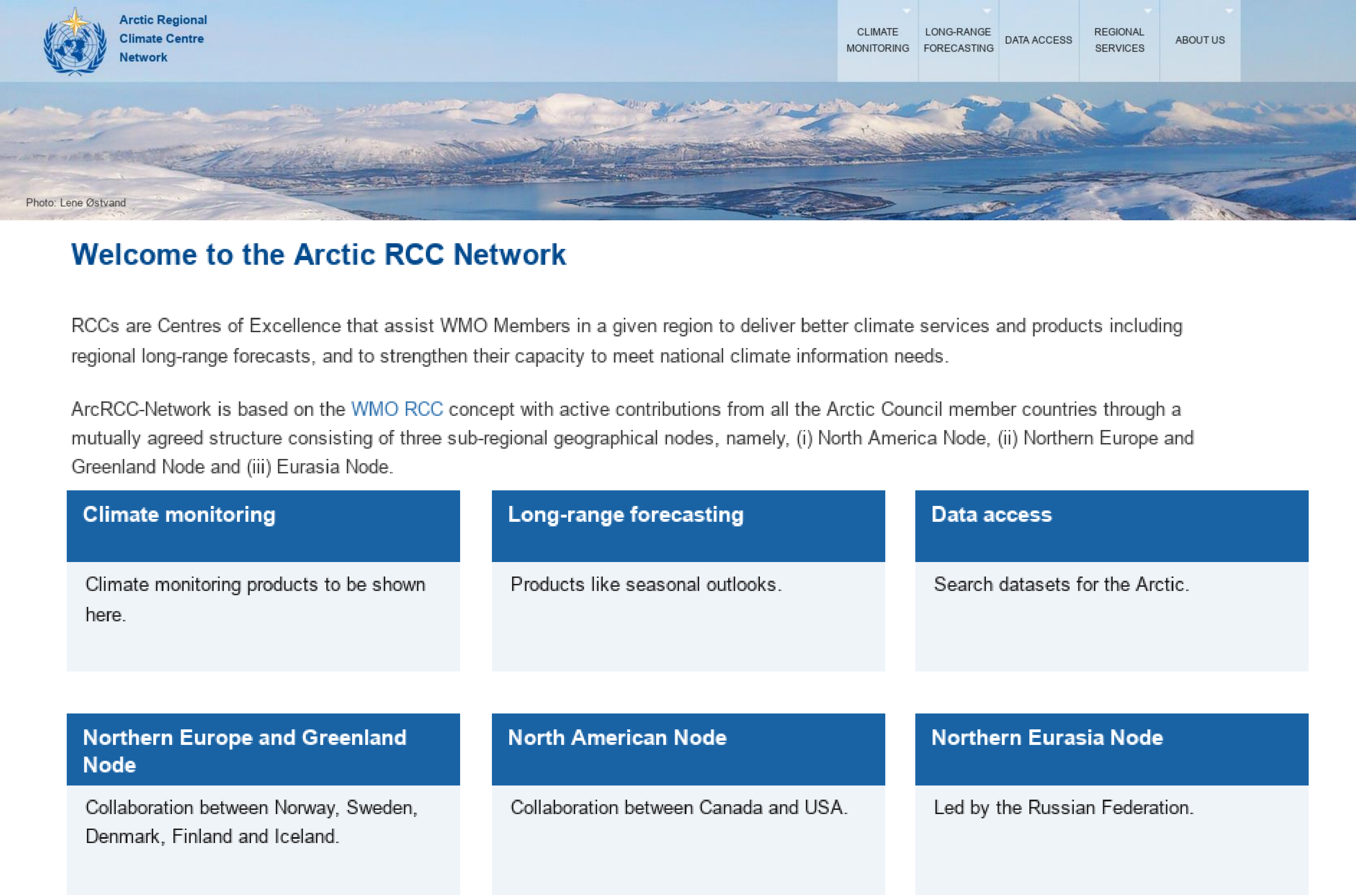
## Lead Centre

WMO Lead Centre for
Long-Range Forecast Multi-Model Ensemble

Latest Forecast data

## Regional Climate Centres (RCCs)

## Regional Climate Outlook Forums (RCOFs)



## Welcome to the Arctic RCC Network

RCCs are Centres of Excellence that assist WMO Members in a given region to deliver better climate services and products including regional long-range forecasts, and to strengthen their capacity to meet national climate information needs.

ArcRCC-Network is based on the WMO RCC concept with active contributions from all the Arctic Council member countries through a mutually agreed structure consisting of three sub-regional geographical nodes, namely, (i) North America Node, (ii) Northern Europe and Greenland Node and (iii) Eurasia Node.

**Climate monitoring**

Climate monitoring products to be shown here.

**Long-range forecasting**

Products like seasonal outlooks.

**Data access**

Search datasets for the Arctic.

**Northern Europe and Greenland Node**

Collaboration between Norway, Sweden, Denmark, Finland and Iceland.

**North American Node**

Collaboration between Canada and USA.

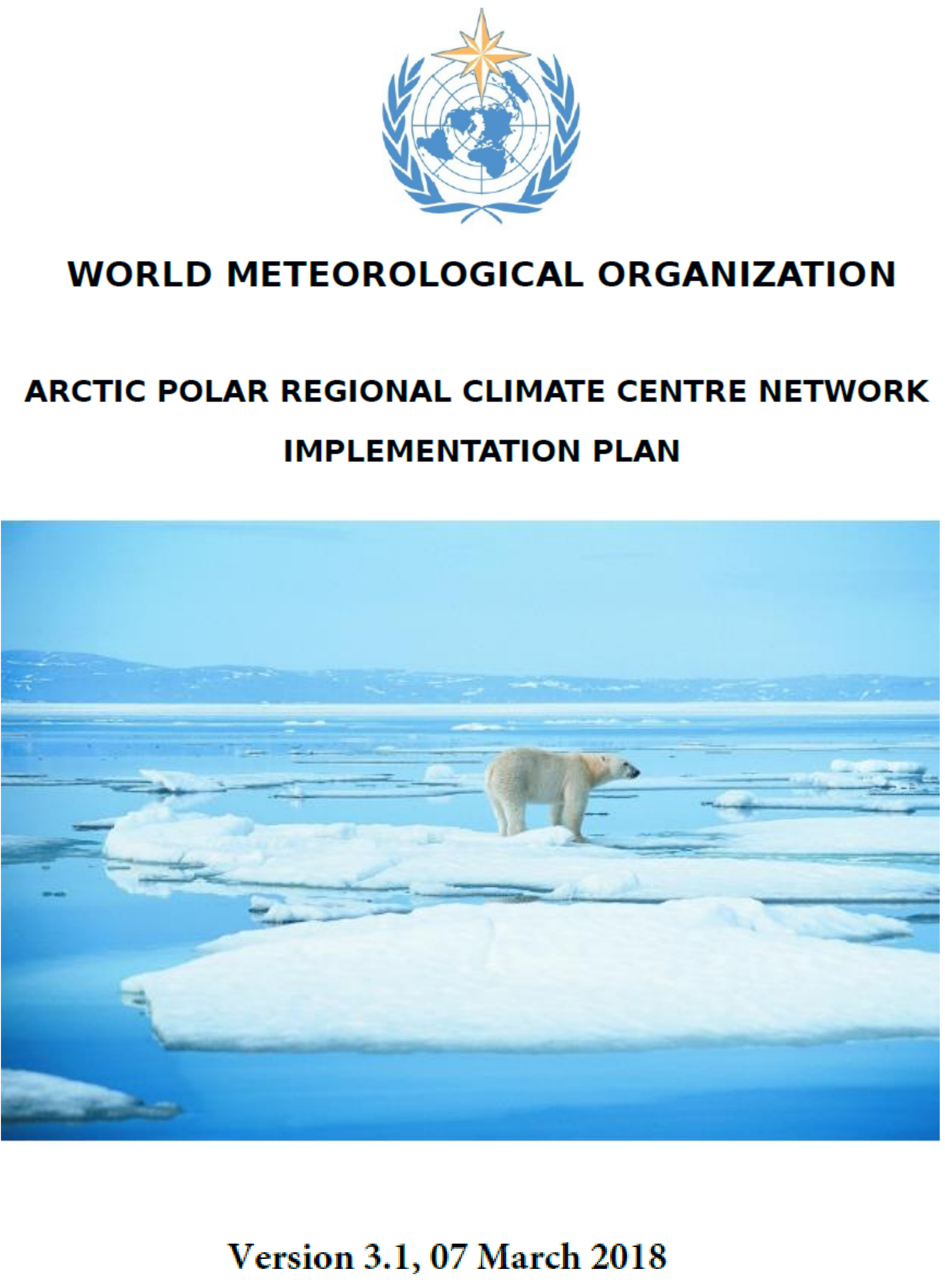
**Northern Eurasia Node**

Led by the Russian Federation.

**Norway: data services**

**Canada: forecast production**

**Russia: climate monitoring**



WORLD METEOROLOGICAL ORGANIZATION

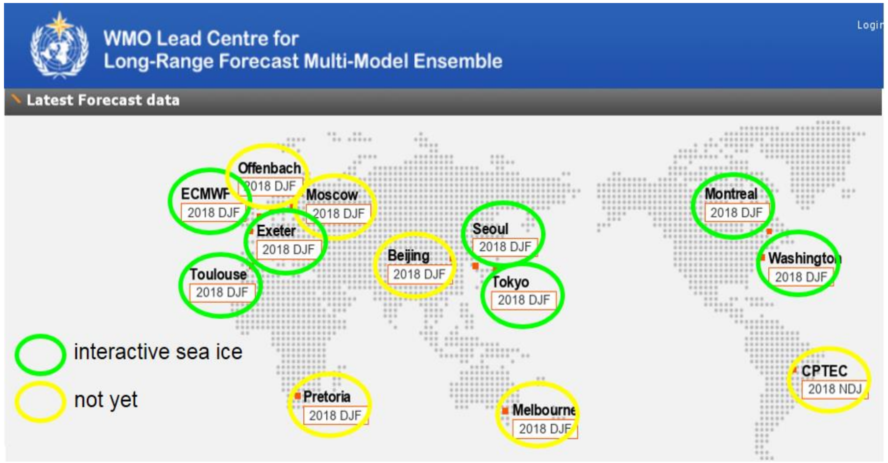
ARCTIC POLAR REGIONAL CLIMATE CENTRE NETWORK

IMPLEMENTATION PLAN

Version 3.1, 07 March 2018

## Annex 13: Technical and administrative roles and responsibilities

***…development and delivery of seamless, reliable and high-quality products and services for the pan-Arctic region including provision of LRF using an MME approach with products of relevance for the whole Arctic (e.g., sea ice)***



# FRAMS overview

- 485k Canadian $ over 3 years  (~2018-2021)
- 1 Postdoc, 1 PhD, 2 MSc

Funded investigators

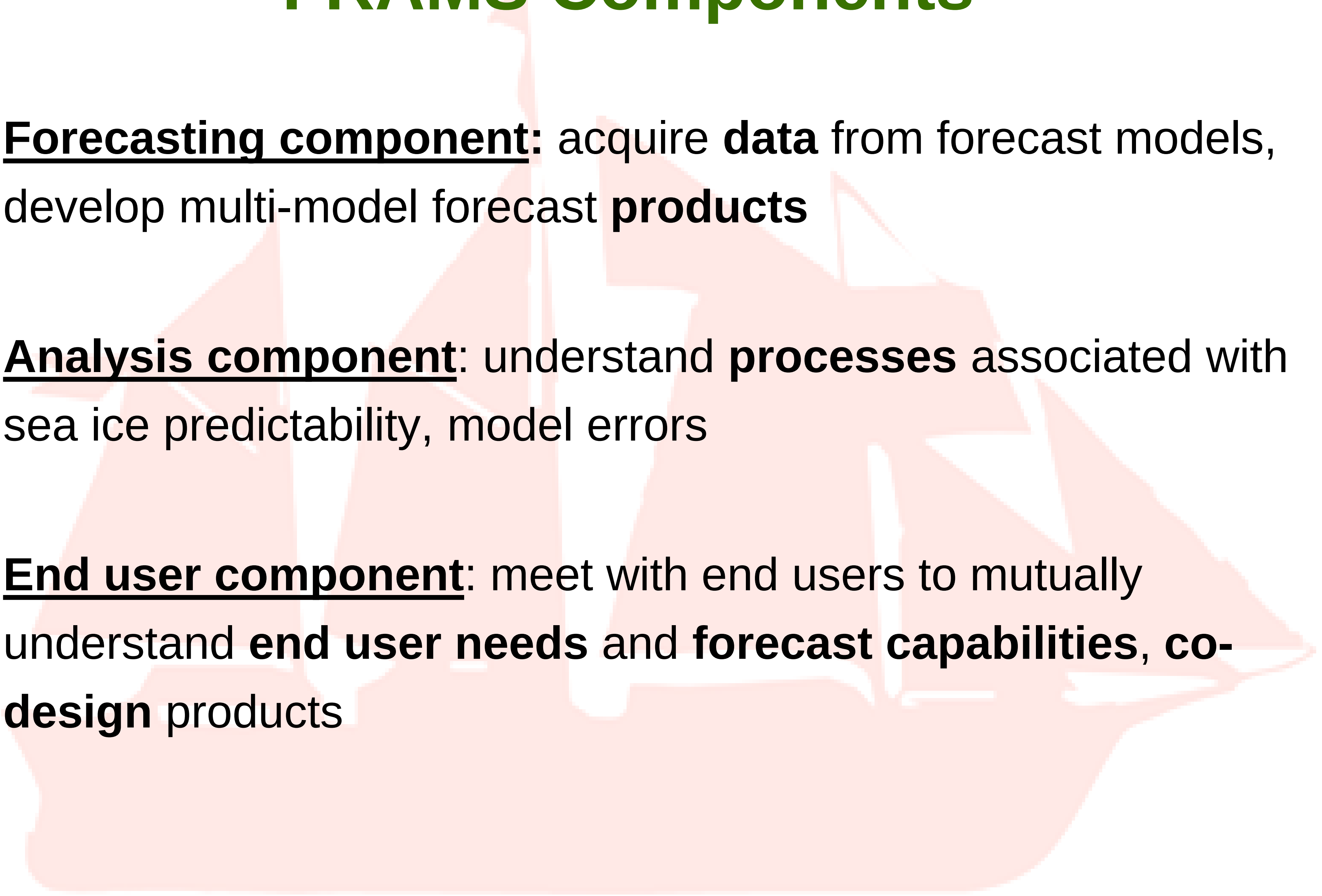
**Bertrand Denis**, ECCC-MSC/UQAM
**Bruno Tremblay**, McGill U.
**Chris Bone**, Geography, U. Victoria
**Bill Merryfield**, ECCC-CCCma/U. Vic.

Collaborators

**Adrienne Tivy**, ECCC-CIS
**Greg Smith**, ECCC-MRD
**Jean-François Lemieux**, ECCC-MRD
**Steve Howell**, ECCC-CRD
**Michael Sigmond**, ECCC-CCCma
**Jackie Dawson**, Geography, U. Ottawa
**Ron Pelot**, Engineering, Dalousie U.

End Users – Fednav, Canadian Coast Guard,…

# FRAMS Components



- **Forecasting component:** acquire **data** from forecast models, develop multi-model forecast **products**

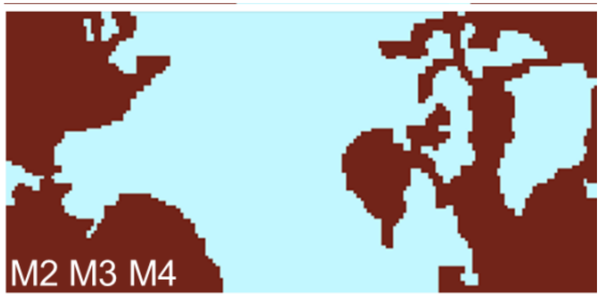
- **Analysis component**: understand **processes** associated with sea ice predictability, model errors

- **End user component**: meet with end users to mutually understand **end user needs** and **forecast capabilities**, **co-design** products

# Forecasting component

## Forecast models

| label | name | centre | sea ice component, rheology | max resolution/range |
|---|---|---|---|---|
| **M1** | CanCM3/4 | MSC | CanICE, cavitating fluid | ≈200 km / 12mon |
| **M2** | GEM-NEMO | MSC | CICE, 5 ice categories, EVP | ≈ 40 km / 12mon |
| **M3** | CFSv2 | NOAA (US) | GFDL SIS, 5 ice categories, EVP | ≈ 40 km / 9 mon |
| **M4** | System 5 | Météo France | GELATO, 4 ice categories, EVP | ≈ 40 km / 6 mon |
| **M5** | GloSea5 | Met Office | CICE, 5 ice categories, EVP | ≈ 10 km / 6 mon |
| **M6** | SEAS5 | ECMWF | LIM2 | ≈ 10 km / 7 mon |
| **M7** | En-GIOPS | MSC | CICE, 10 ice categories, EVP | ≈ 10 km / 1 mon |

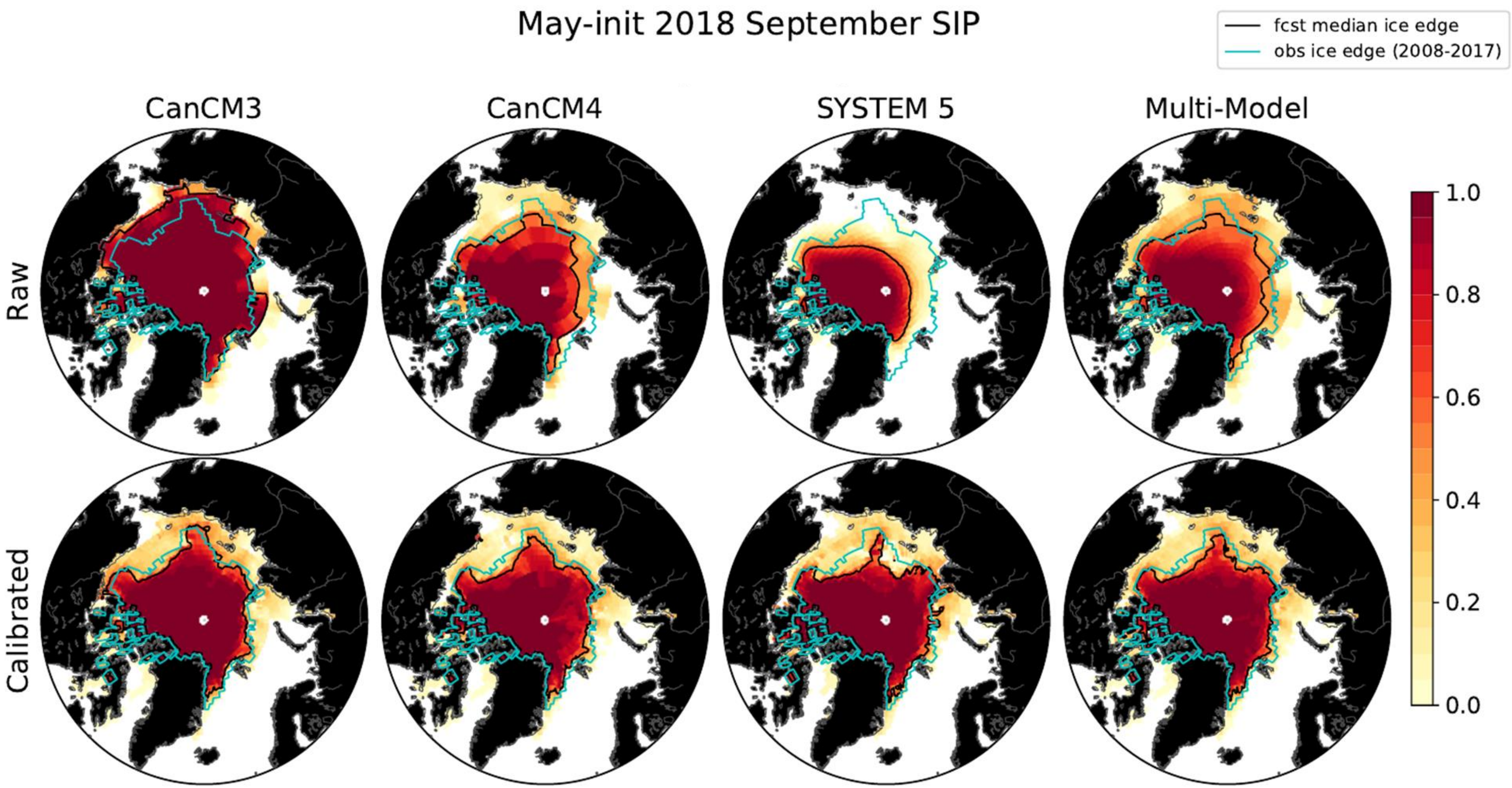


## Forecast products

| Forecast element | Purpose |
|---|---|
| **Ice extent/area** | benchmark for comparison with previous studies |
| * **Sea ice probability (SIP)** | probability of local concentration exceeding user-defined thresholds |
| * **Ice-free/freeze-up dates** | timing of local seasonal ice retreat and advance |
| **Canadian Ice Service outlook** | Model-based CIS Seasonal Outlook, updated based on user inputs |
| **Shipping-relevant products** | innovative tailored products incorporating feedback from end users |

# Calibrated Sea Ice Probability: P(SIC>15%)

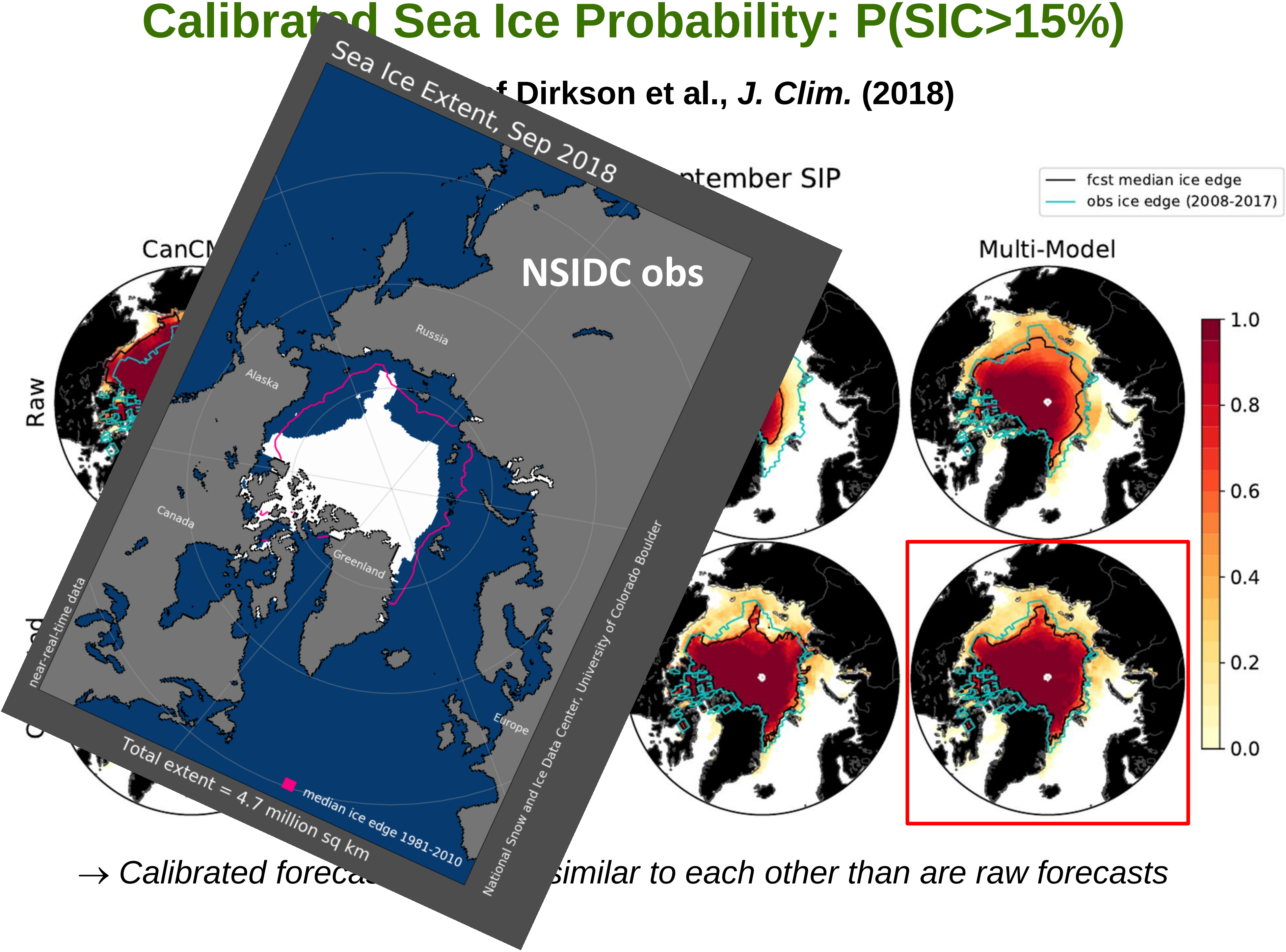
**Method of Dirkson et al., *J. Clim.* (2018)**



→ *Calibrated forecasts far more similar to each other than are raw forecasts*

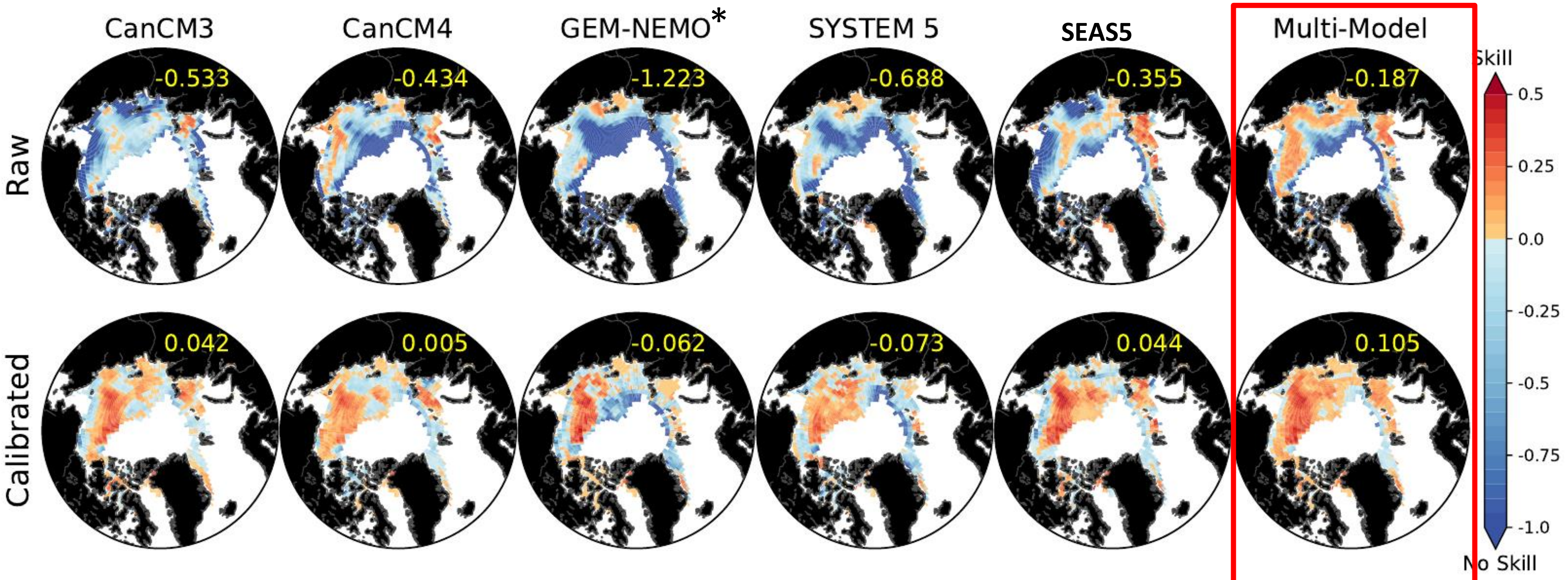
# Calibra ed Sea Ice Probability: P(SIC>15%)

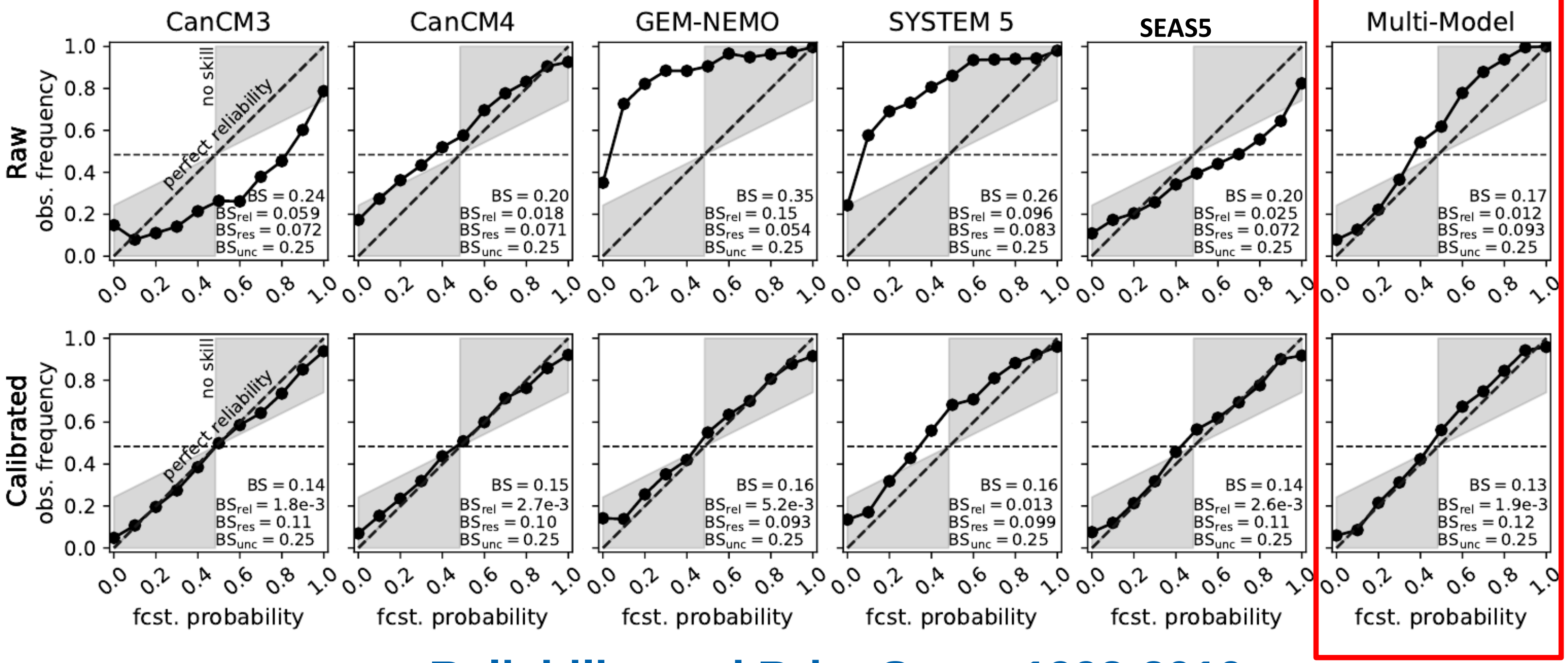
f Dirkson et al., *J. Clim.* (2018)



→ *Calibrated foreca* *similar to each other than are raw forecasts*

# Continuous Rank Probability Skill Score (CRPSS) vs climatology 1993-2010





***September from May***

*developmental version

## Reliability and Brier Score 1993-2010

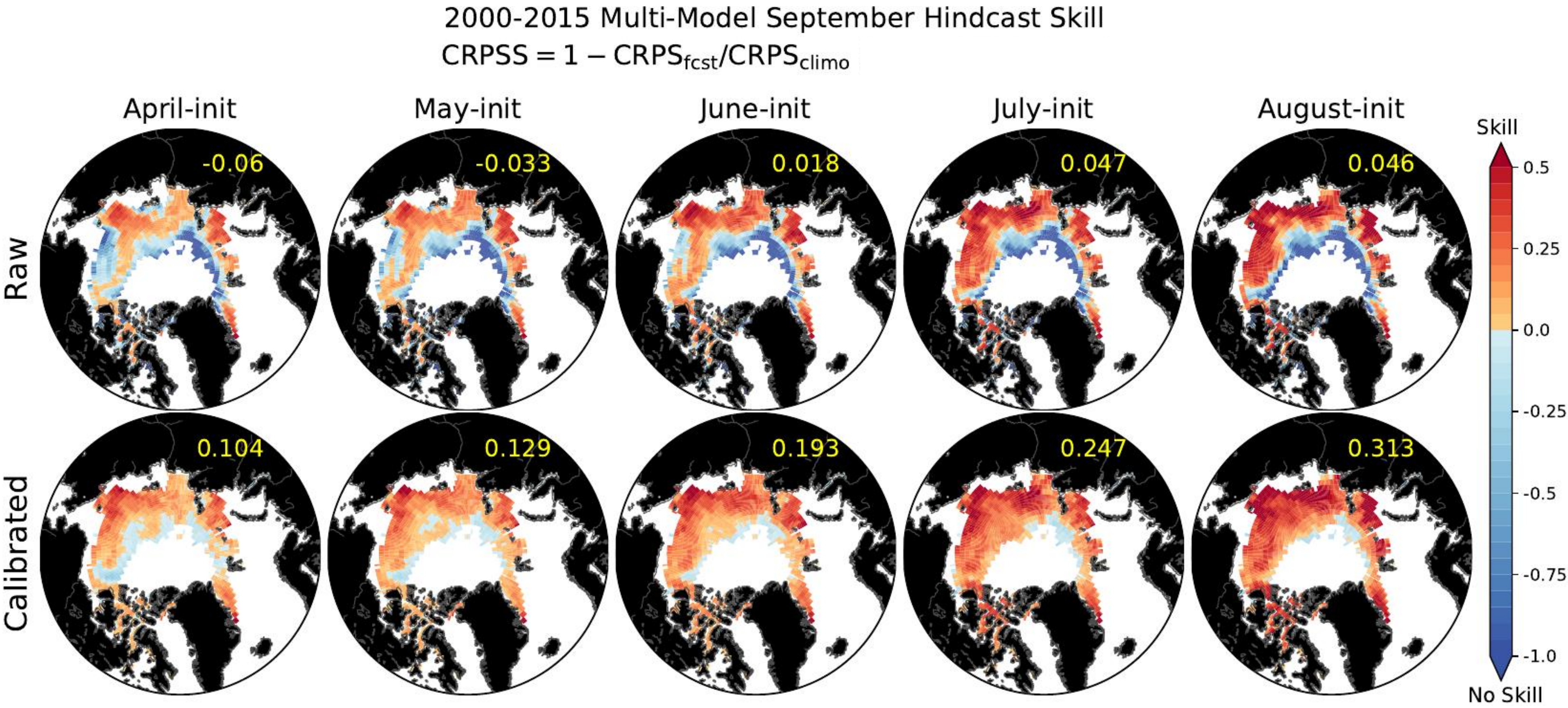
***A. Dirkson plots***

# Available GPCs + GFDL-FLOR

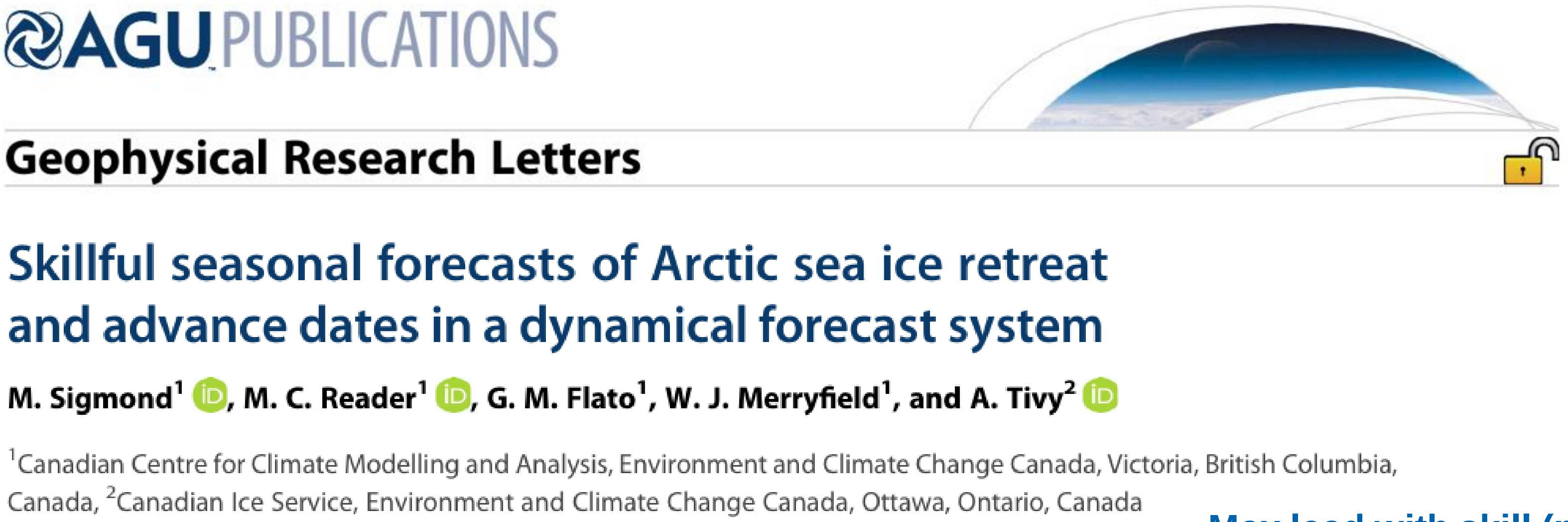
## Sep Multi-Model CRPSS vs initialization month

**ECMWF** **Met Office** **MF** **ECCC** **(GFDL)**

**SEAS5 + GloSea5 + System 5 + CanSIPS + FLOR**



*Dirkson et al. in preparation*



AGU PUBLICATIONS

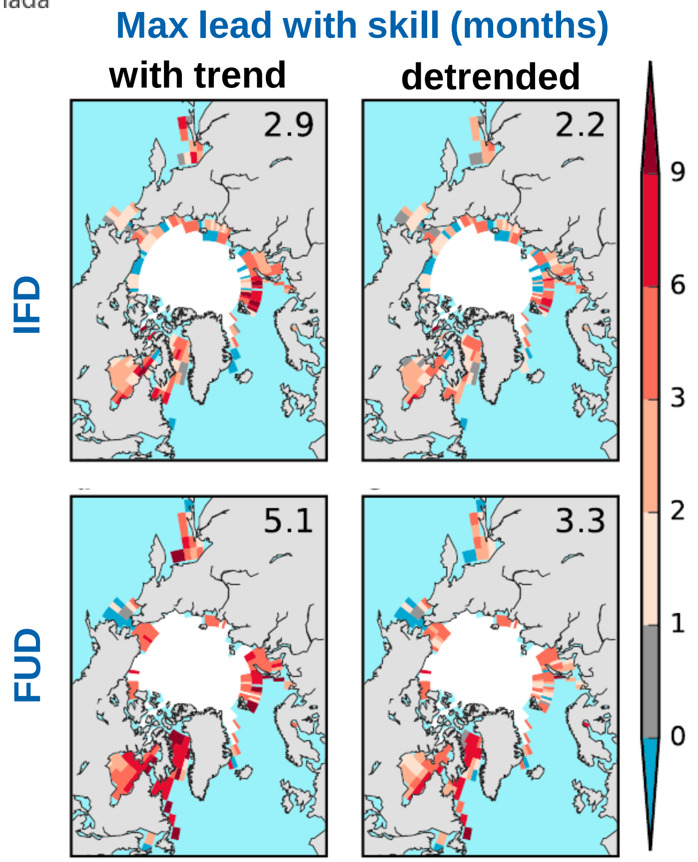
Geophysical Research Letters

# Skillful seasonal forecasts of Arctic sea ice retreat and advance dates in a dynamical forecast system

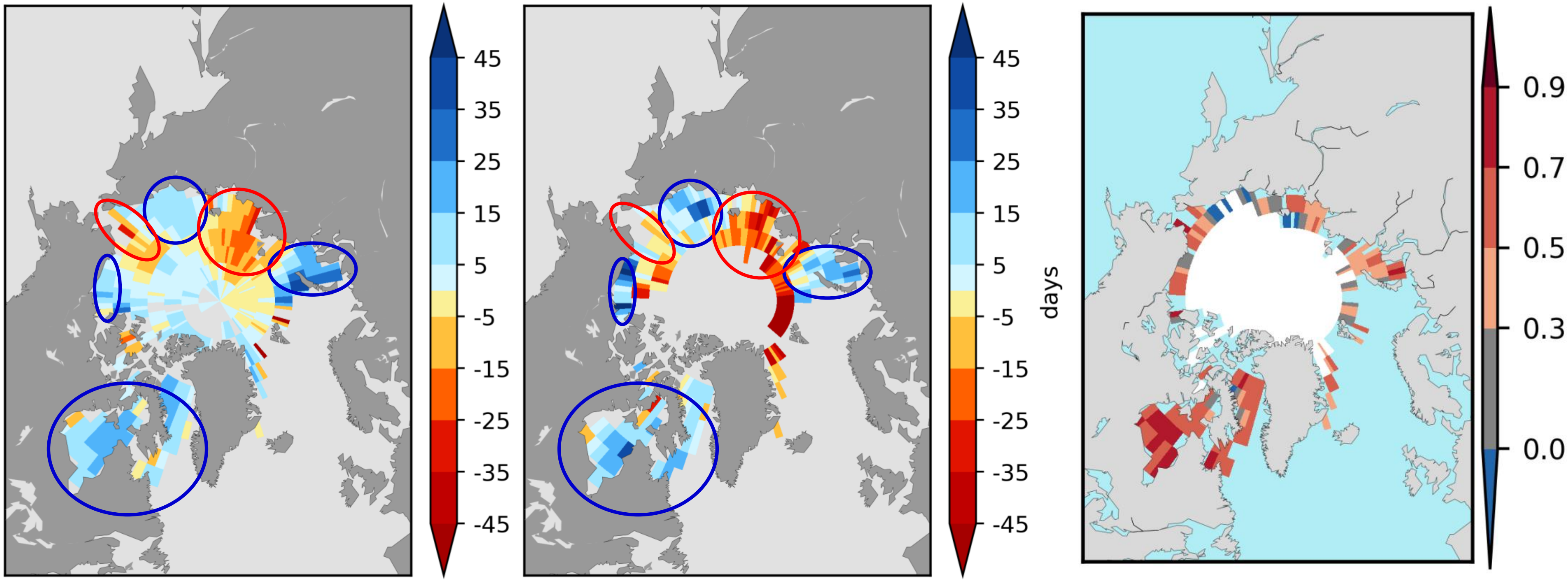
M. Sigmond[1], M. C. Reader[1], G. M. Flato[1], W. J. Merryfield[1], and A. Tivy[2]

[1]Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Victoria, British Columbia, Canada, [2]Canadian Ice Service, Environment and Climate Change Canada, Ottawa, Ontario, Canada

- Define
  - Ice-free date (**IFD**) : SIC<50% for ≥10 days
  - Freeze-up date (**FUD**): SIC>50% for ≥10 days
- FUD more skillful than IFD
- Requires daily SIC



# Ice-free date forecast, 31 May 2018 initialization



Forecast anomaly
(base: 2009-17)

Observed anomaly
(base: 2009-17)

Historical skill
(detrended ACC for 1981-2010)

- Correctly predicted the **late** ice-free dates in Hudson Bay and Baffin Bay

- Also correctly predicted **late** ice-free date in Kara, E Siberian and Beaufort seas, and **early** ice-free date in Laptev and Chukchi Seas

***M. Sigmond plots***

# FRAMS outputs are contributing to WMO PARCOFs

Environment and Climate Change Canada

Norwegian Meteorological Institute

Russian Federal Service for Hydrometeorology and Environmental Monitoring

WORLD METEOROLOGICAL ORGANIZATION

## Second Session of the Pan-Arctic Regional Climate Outlook Forum (PARCOF-2), virtual forum, October 2018

Consensus Statement for the Arctic Winter 2018-2019 Season Outlook

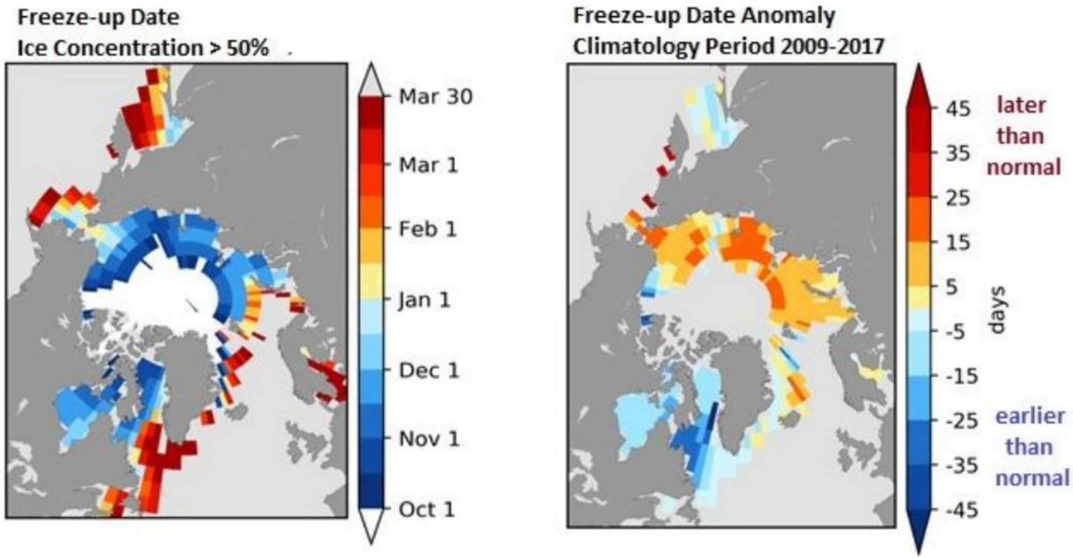


**Figure 10:** Forecast for the 2018 Fall freeze-up (a) actual freeze-up date and (b) anomaly (difference from normal) based on the 2009-2017 period. The freeze-up date is first day when the ice concentration exceeds 50%

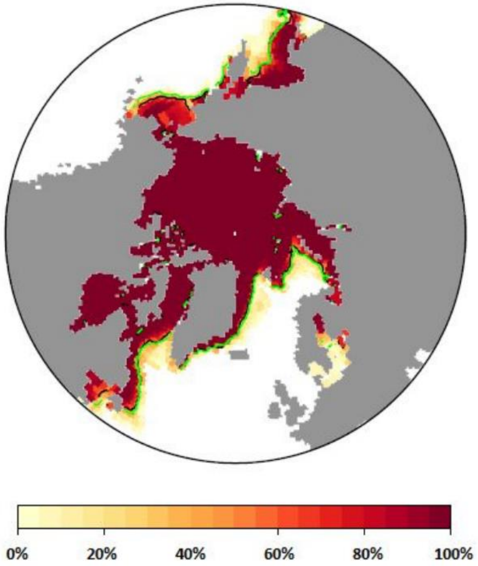
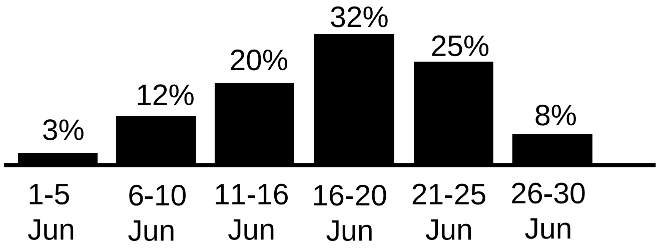


**Figure 11:** March 2019 probability of sea ice at concentrations greater than 15% from CanSIPS (ECCC). Ensemble mean ice extent from CanSIPS (black) and observed mean ice extent 1998-2017 (green)

# Next steps

- **Real time multi-model** SIP & IFD/FUD forecasts for ArcRCC/PARCOF
- **Probabilistic IFD/FUD forecasts** →

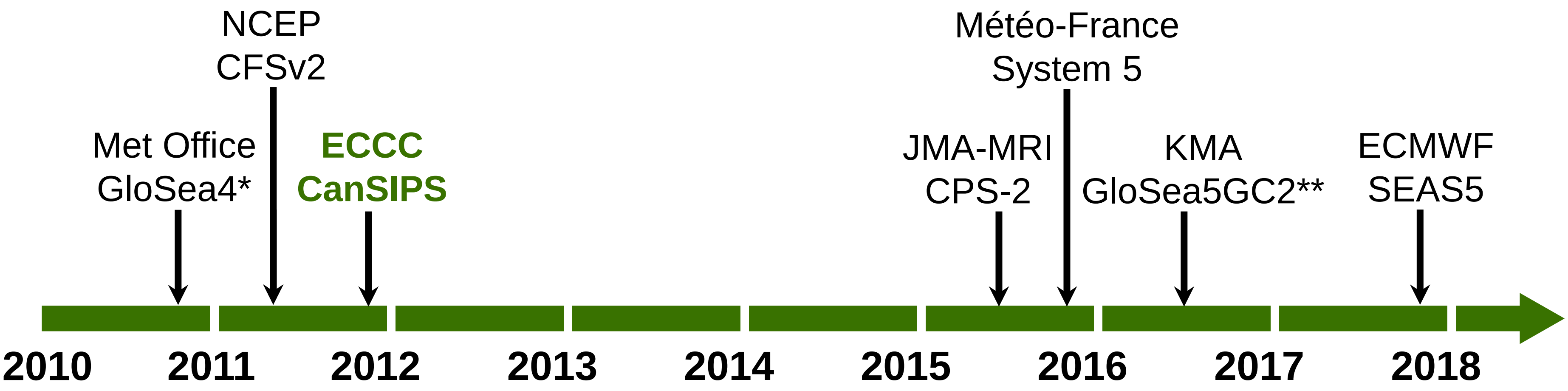


- **Bias correction of Polar Pathfinder** ice motion vectors
- **Evaluate ice drift forecasts** using bias corrected Polar Pathfinder as truth
- **WMS-based visualization** of forecast & sea ice information
- **Upgrade Canadian Ice Service outlooks** using model-based predictors

# Extra slides

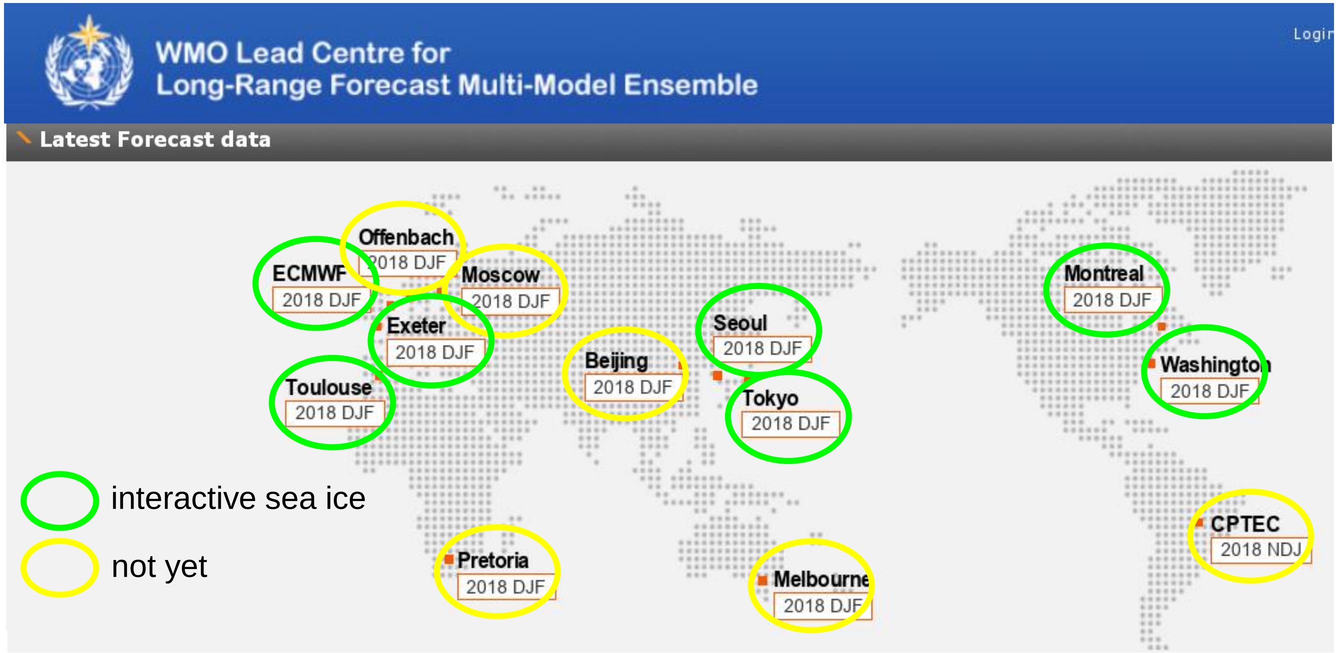
# Timeline for seasonal sea ice forecasting

*WMO operational models*



*1st operational seasonal prediction system with interactive sea ice

**mirrors current Met Office system


WMO Lead Centre for
Long-Range Forecast Multi-Model Ensemble

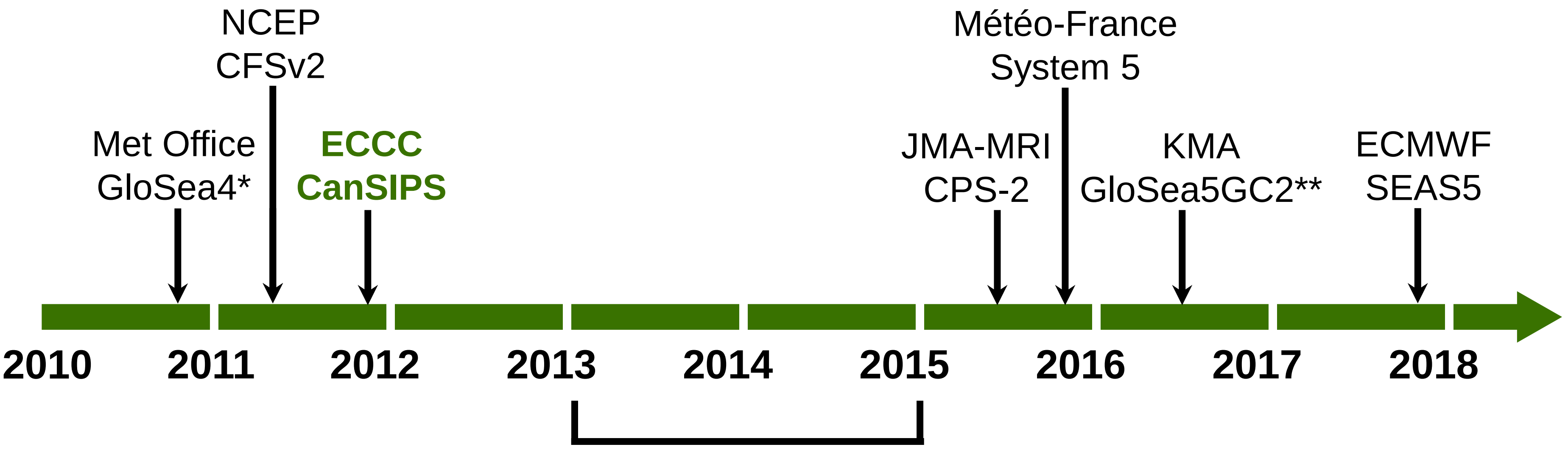
Latest Forecast data

🟢 interactive sea ice

🟡 not yet

# Timeline for seasonal sea ice forecasting

***Scientific literature***



Met Office
GloSea4*

NCEP
CFSv2

**ECCC**
**CanSIPS**

JMA-MRI
CPS-2

Météo-France
System 5

KMA
GloSea5GC2**

ECMWF
SEAS5

**2010** **2011** **2012** **2013** **2014** **2015** **2016** **2017** **2018**

**Forecasts of pan-Arctic sea ice extent/area**
**(deterministic forecasts of anomalies)**

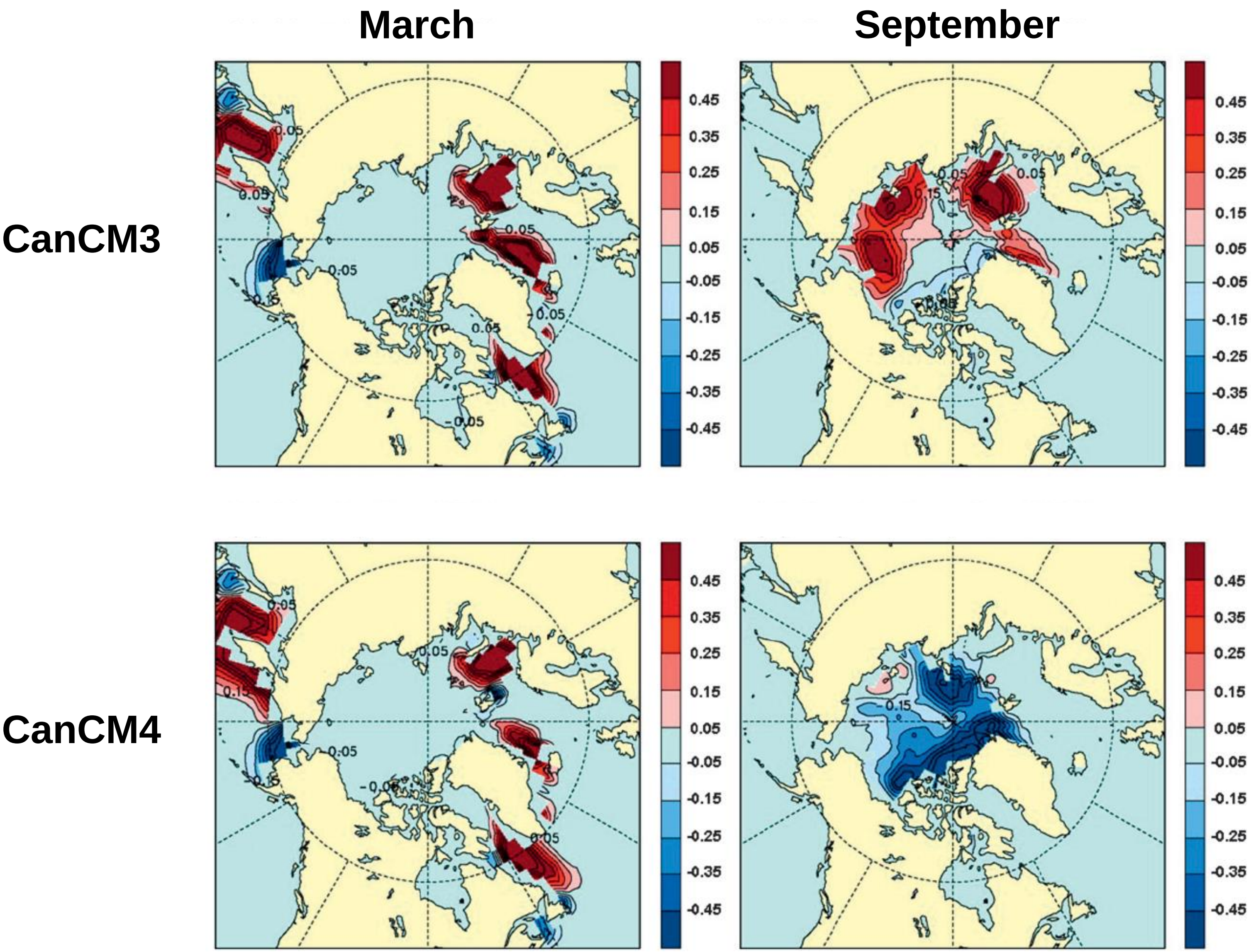
**Wang et al. (2013) CFSv2**
**Sigmond et al. (2013) CanSIPS**
**Merryfield et al. (2013) CanSIPS + CFSv2**
**Chevallier et al. (2013) pre-MF System 5**
**Peterson et al. (2014) GloSea4**

# Seasonal forecasting challenges specific to sea ice

1) **Initialization**, especially of ice thickness
2) **Consistency** of initialization between hindcasts & real-time forecasts
3) **Bias correction** for concentration variable defined on [0,1]
4) **Fitting and calibration** of distribution defined on [0,1]

# CanCM3/4 sea ice concentration biases

*Freely running model 1981-2010 vs HadISST1.1*



**March**

**September**

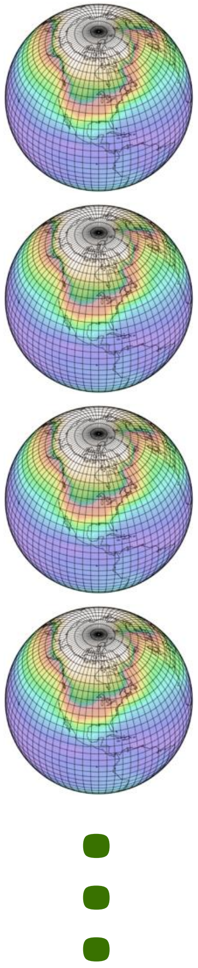
**CanCM3**

**CanCM4**

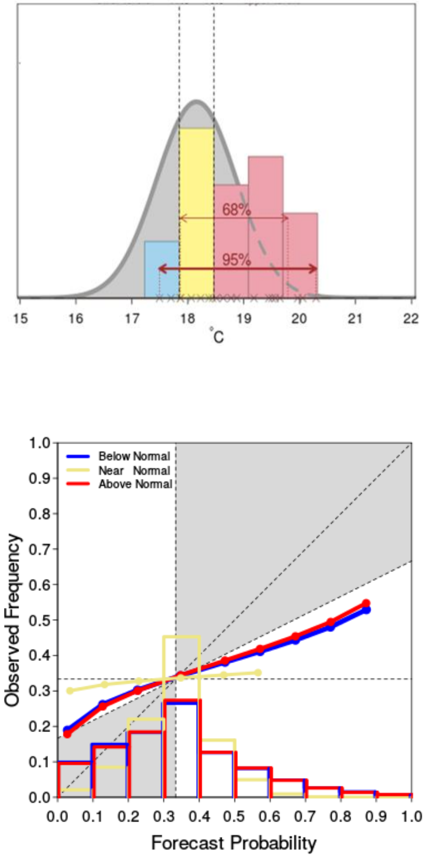
*Merryfield et al. MWR (2013)*

# Standard procedures for seasonal forecasting

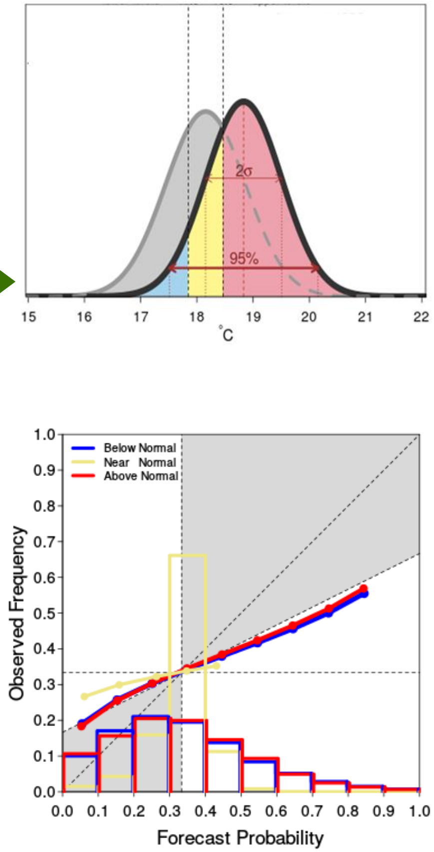
**Ensemble of initialized forecast runs**



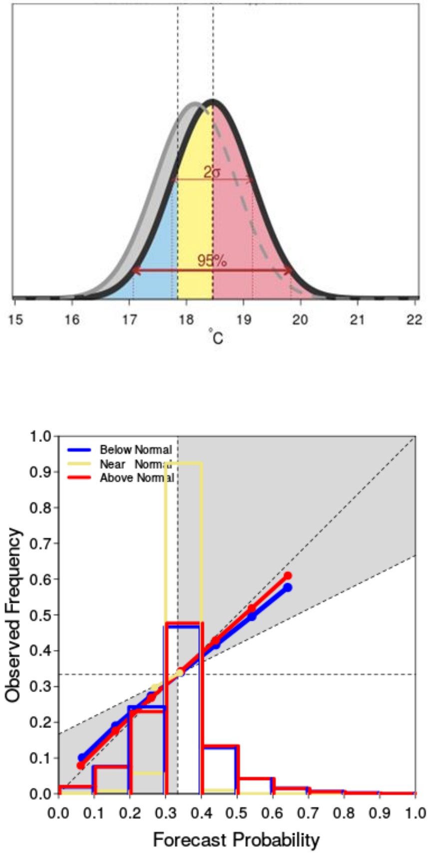
**Bias correction, calculation of anomalies**



**Fit raw anomalies to distribution**

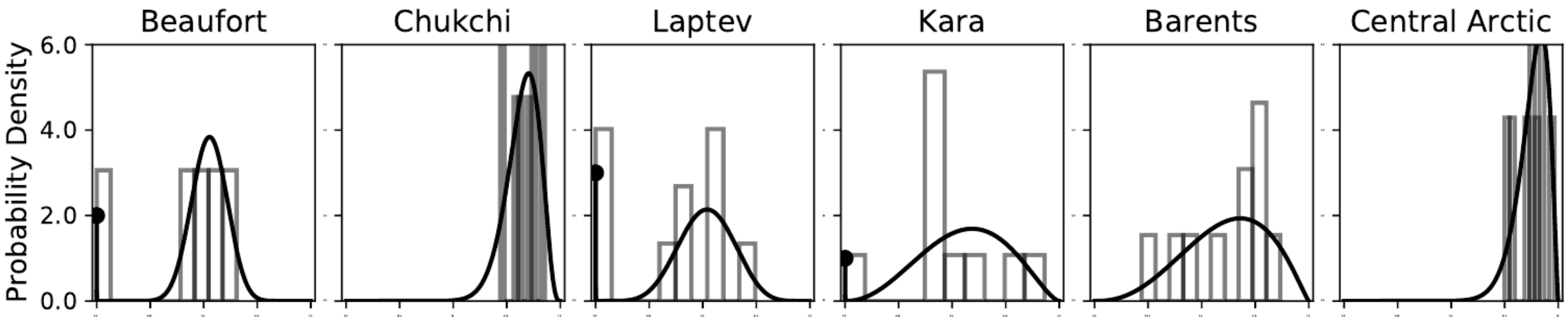


**Calibrate fitted distribution**

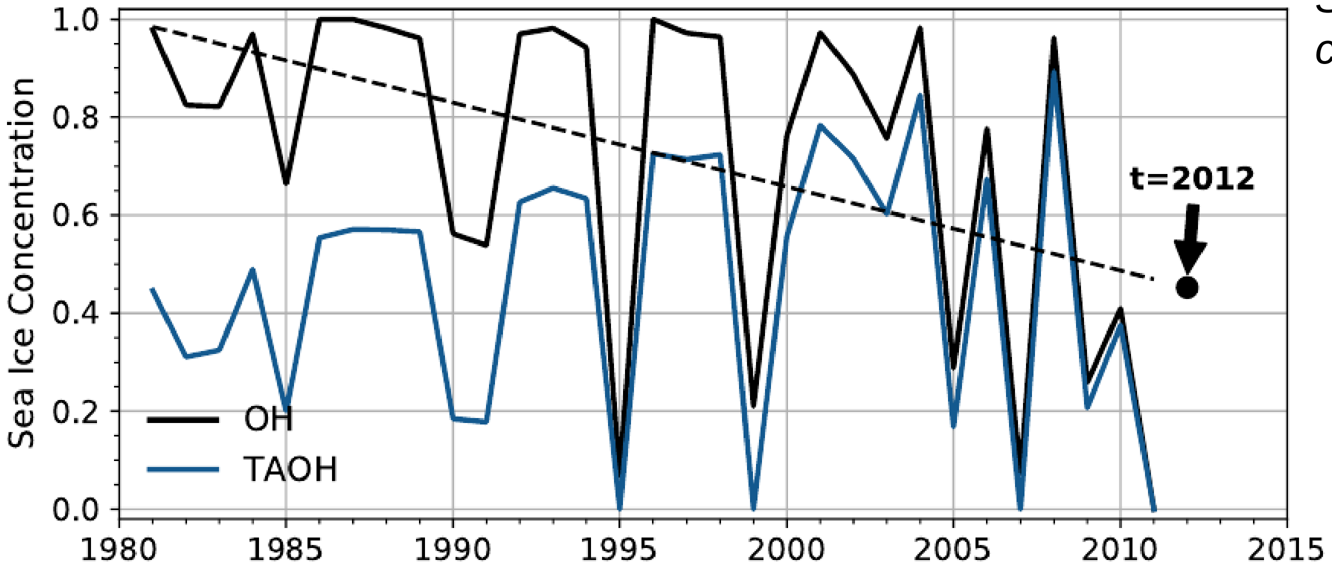


# Sea ice probabilistic forecast method

**Step 1**: Fit “count” concentrations to **inflated beta distributions** on [0,1]



**Step 2**: Calibrate forecast distribution through *trend adjusted quantile mapping* derived from hindcasts:



*Sep SIC for grid cell in Laptev Sea*

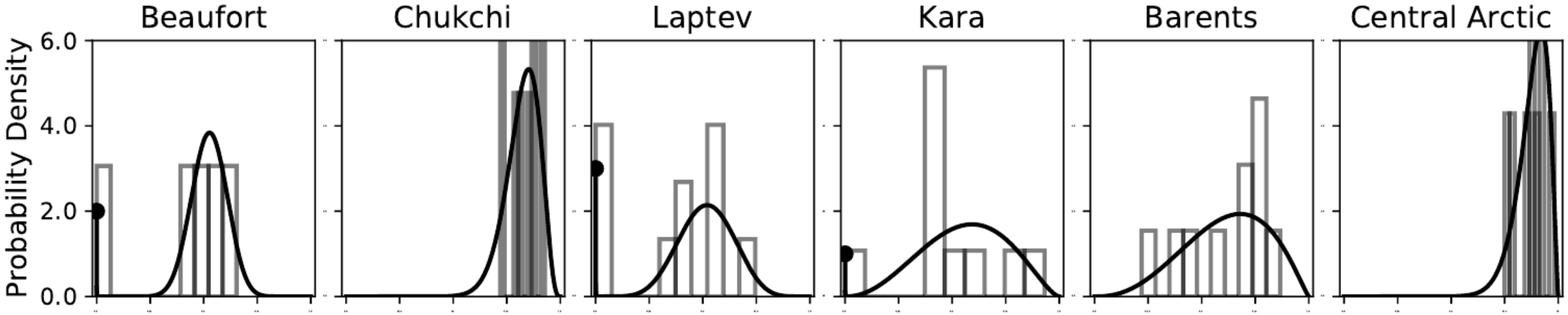
**Observed**

**Trend-adjusted**

***Dirkson et al. J. Clim.* 2018**

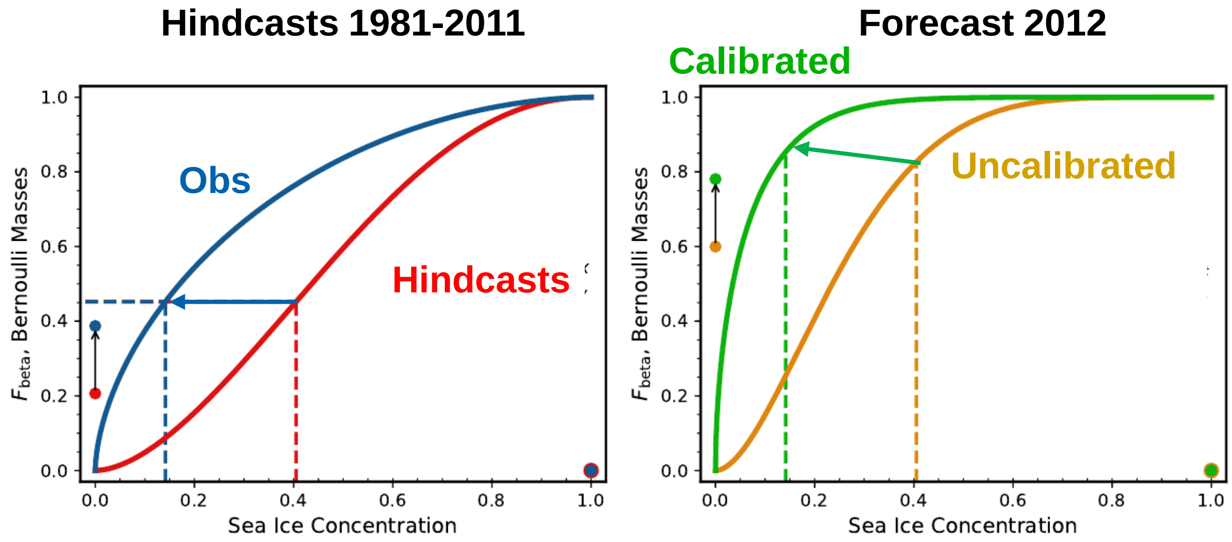
# Sea ice probabilistic forecast method

**Step 1**: Fit "count" concentrations to **inflated beta distributions** on [0,1]



**Step 2**: Calibrate forecast distribution through *trend adjusted quantile mapping* derived from hindcasts

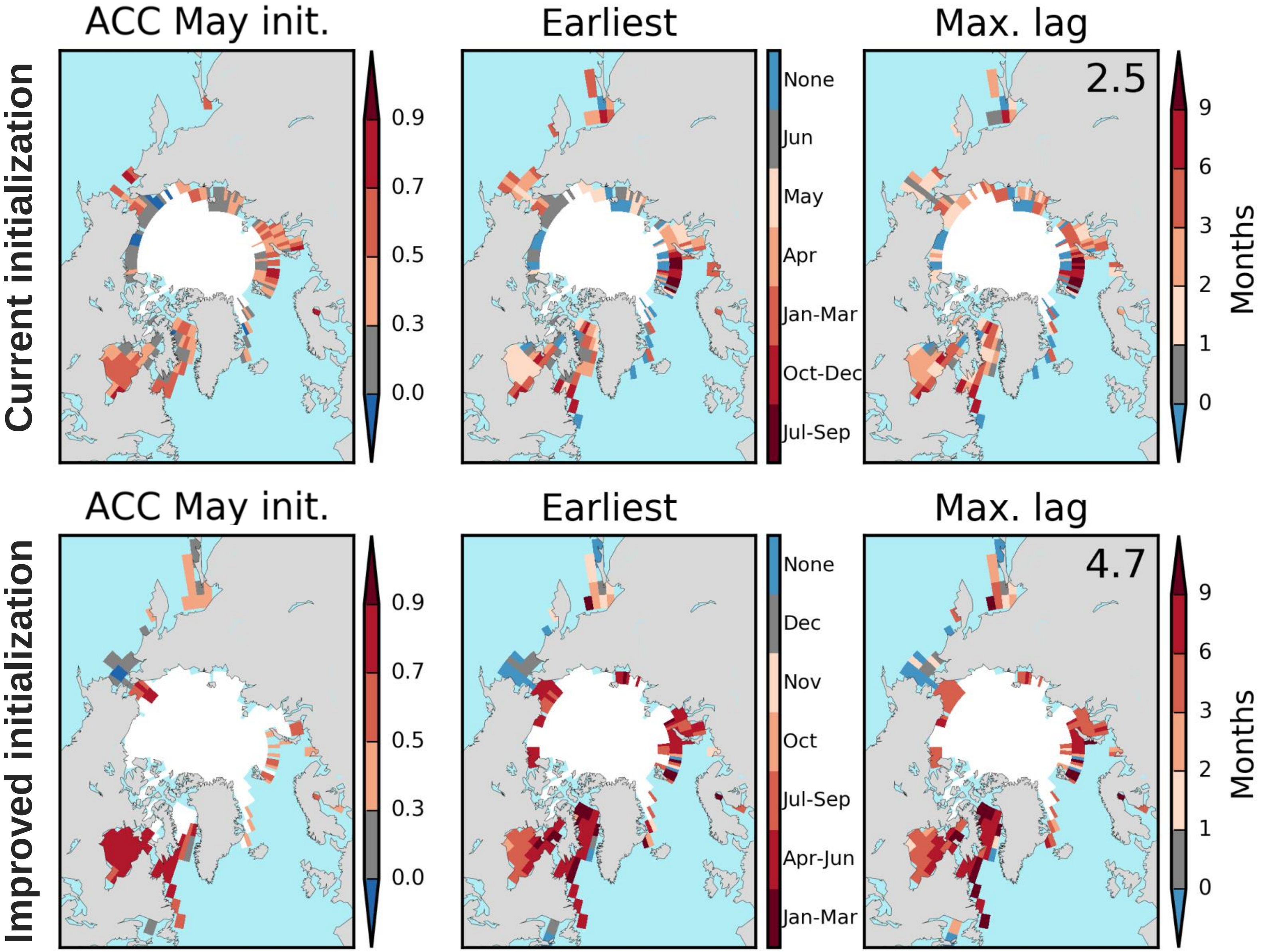
**Trend-adjusted CDFs for Sep SIC from Jun**



***Dirkson et al. J. Clim.*** **2018**

# Ice-Free Date skill

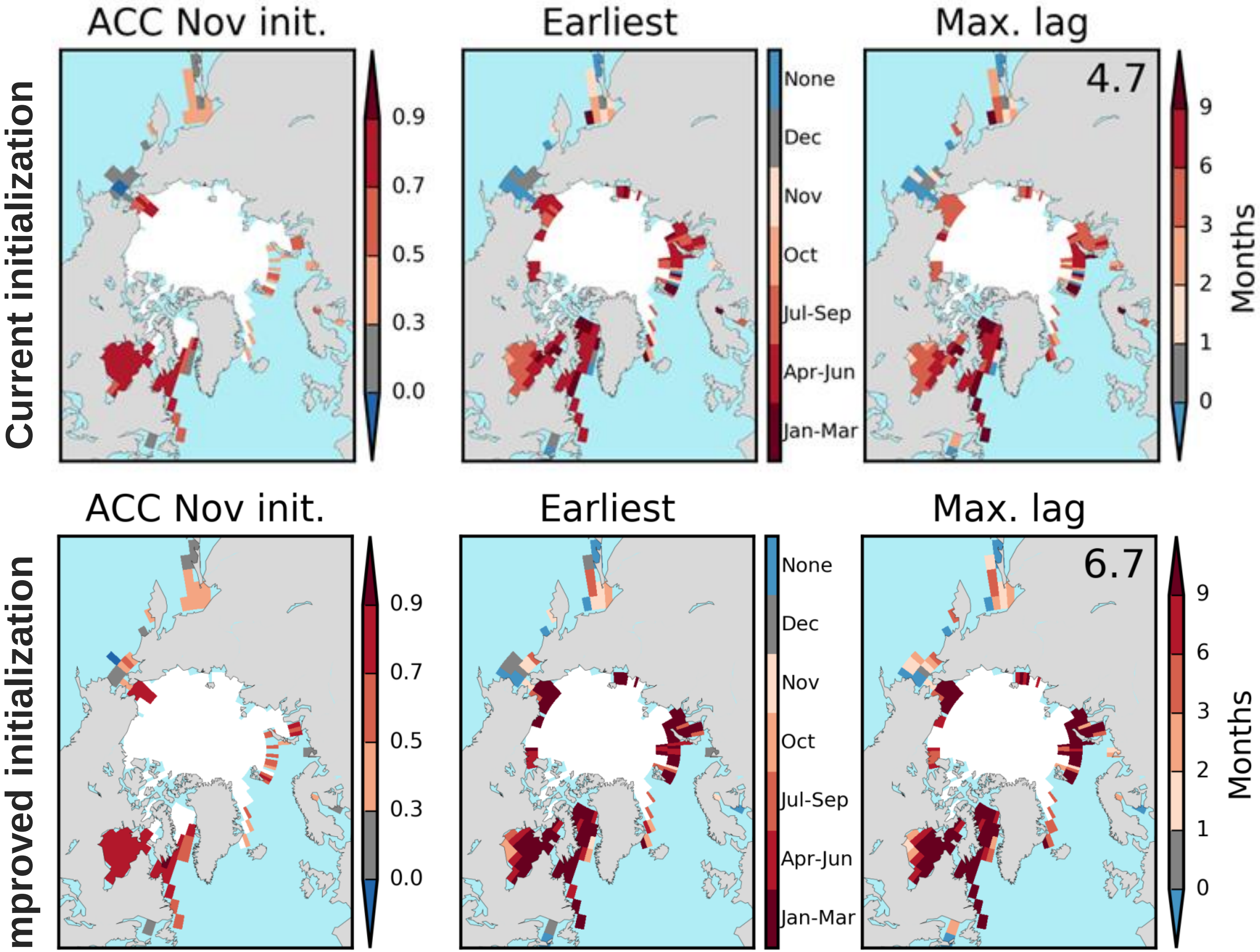
***Based on anomaly correlation coefficient (ACC)***



***M. Sigmond plots***

# Freeze-Up Date skill

***Based on anomaly correlation coefficient  (ACC)***



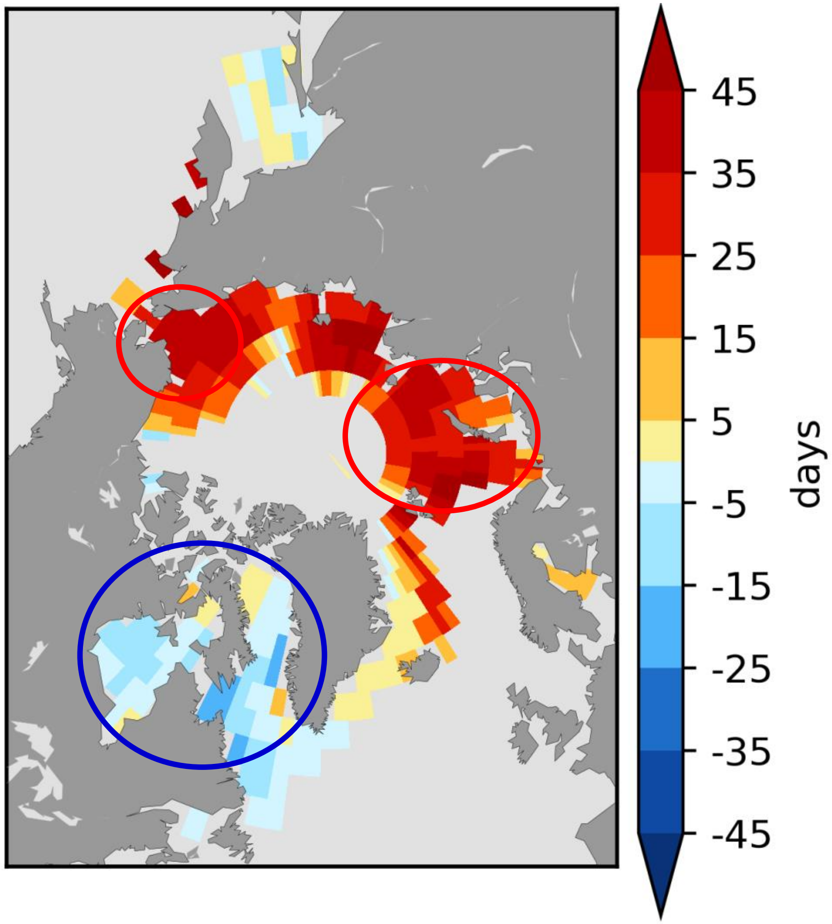
***M. Sigmond plots***

# Freeze-up date, 30 Sep 2018 initialization

## *Forecast and current ice edge*

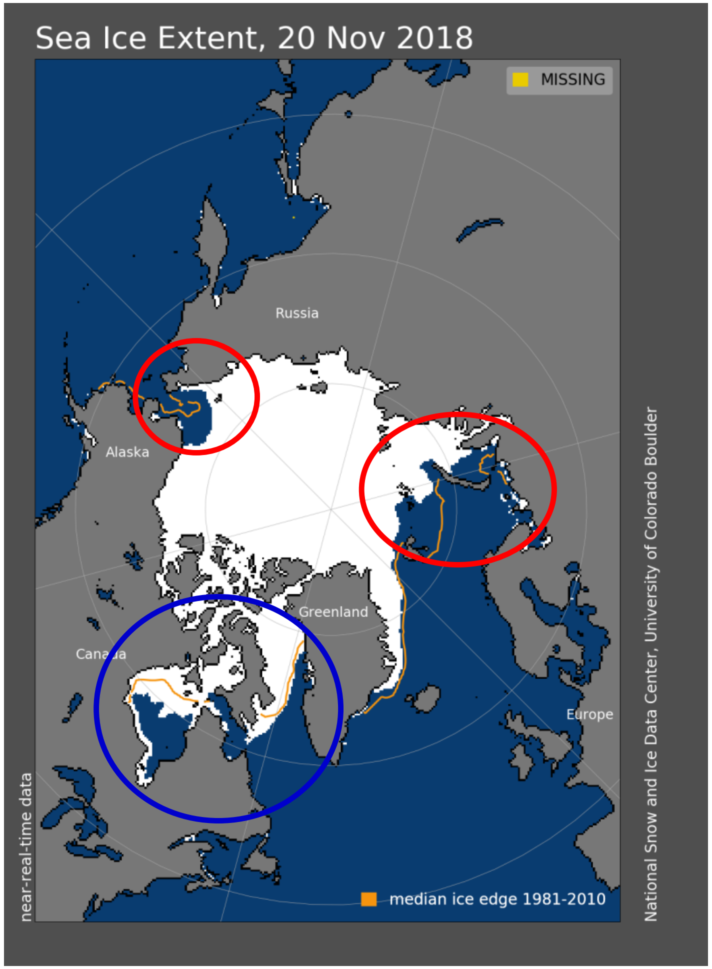
Forecast anomaly

**base period: 1981-2010**



— Median ice edge

**1981-2010**

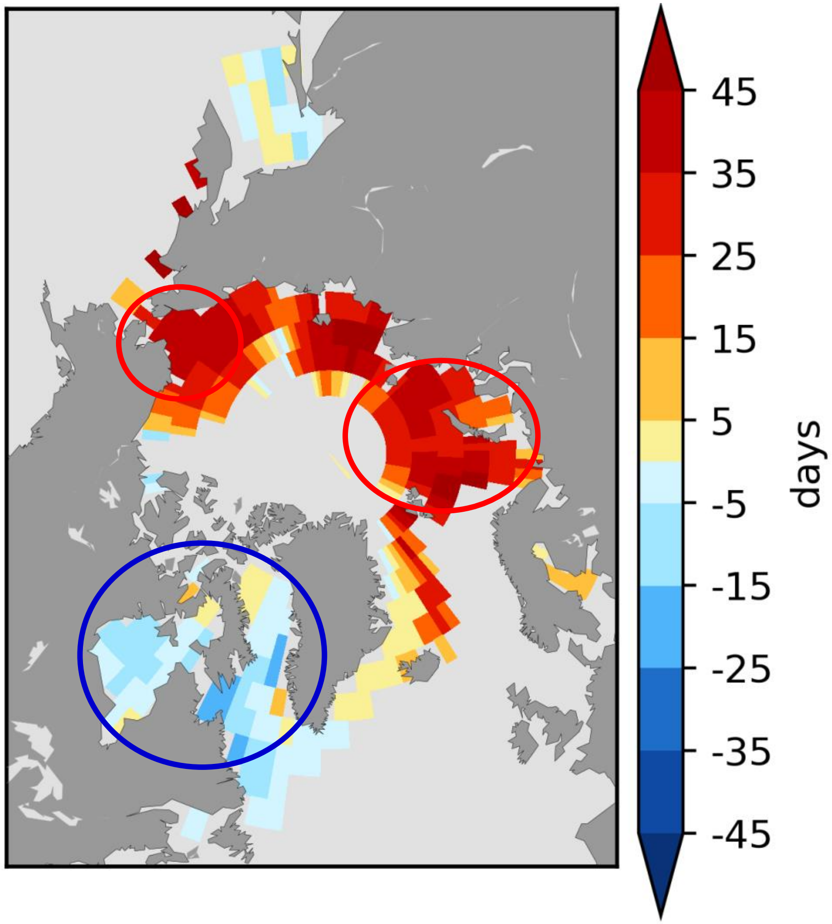


# Freeze-up date, 30 Sep 2018 initialization

## *Forecast and skill*

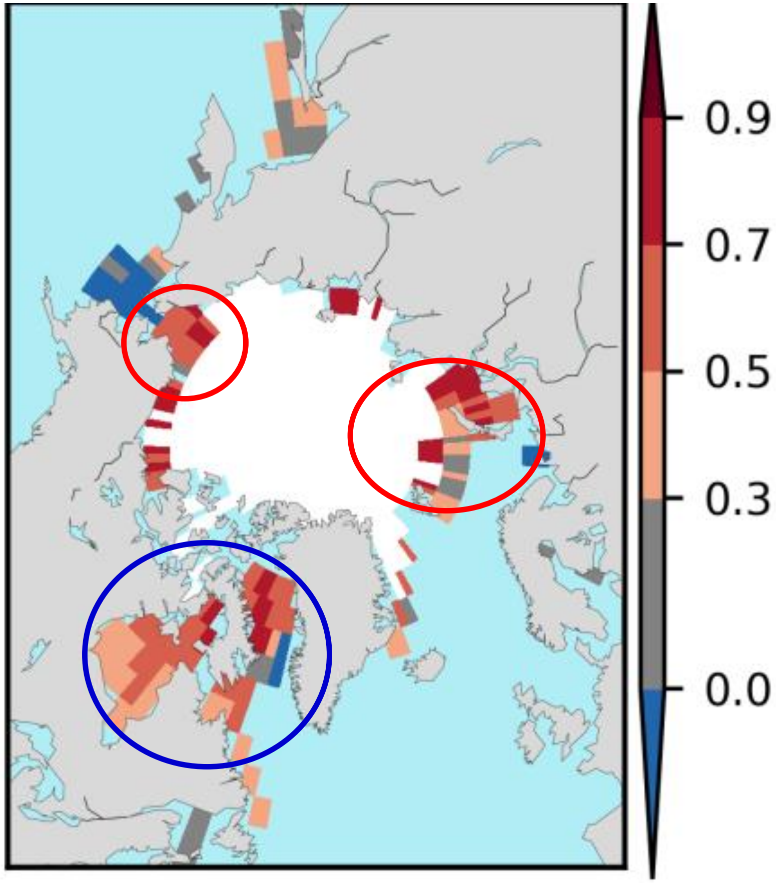
### Forecast anomaly

**base period: 1981-2010**



### Historical skill

**detrended ACC for 1981-201**



→ Regions where early or late ice edge observed are relatively skillful

Environment and Climate Change Canada

Norwegian Meteorological Institute

Russian Federal Service for Hydrometeorology and Environmental Monitoring

WORLD METEOROLOGICAL ORGANIZATION

# Second Session of the Pan-Arctic Regional Climate Outlook Forum (PARCOF-2), virtual forum, October 2018

## Consensus Statement for the Arctic Winter 2018-2019 Season Outlook

Fall Freeze-up

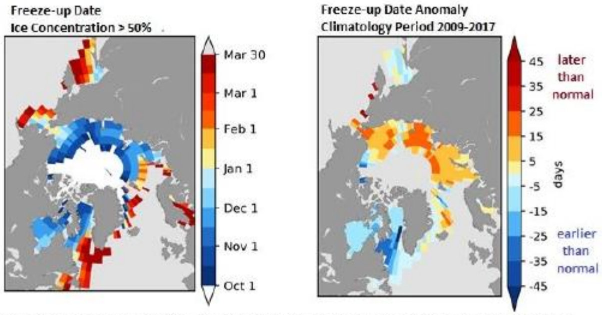


**Figure 10:** Forecast for the 2018 Fall freeze-up (a) actual freeze-up date and (b) anomaly (difference from normal) based on the 2009-2017 period. The freeze-up date is first day when the ice concentration exceeds 50%

| Region | Fall freeze-up | Confidence |
|---|---|---|
| Hudson Bay/Baffin Bay/Labrador Sea | earlier than normal | [moderate to high confidence] |
| Gulf of St. Lawrence | near normal | [low confidence] |
| Greenland Sea | near normal | [moderate confidence] |
| Barents Sea | later than normal | [moderate confidence] |
| Kara/Laptev/East Siberian Seas | later than normal | [moderate to high confidence] |
| Chukchi Sea | later than normal | [high confidence] |
| Beaufort Sea | earlier than normal | [high confidence] |
| Sea of Okhotsk | near normal | [low confidence] |
| Bering Sea | later than normal | [low confidence] |

**Table 1:** 2018 Outlook for fall freeze up by region

March 2019 Sea Ice Extent:

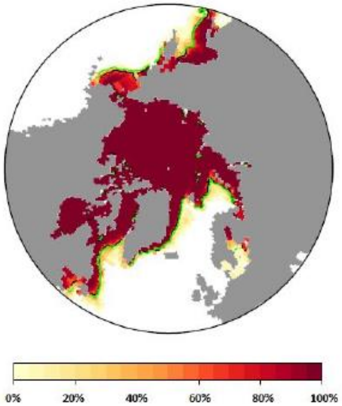


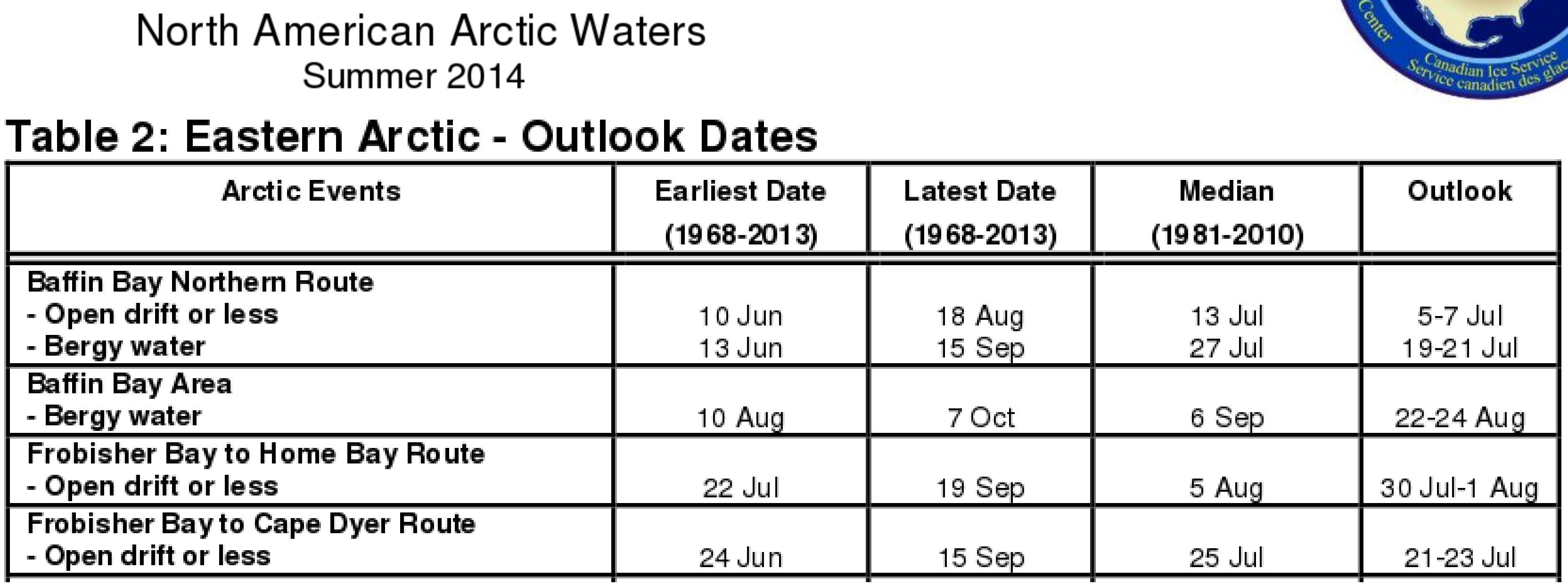
**Figure 11:** March 2019 probability of sea ice at concentrations greater than 15% from CanSIPS (ECCC). Ensemble mean ice extent from CanSIPS (black) and observed mean ice extent 1998-2017 (green)

| Region | Sea-ice extent | Confidence |
|---|---|---|
| Greenland Sea | near normal | [low confidence] |
| Gulf of St. Lawrence | below normal | [low confidence] |
| Bering Sea | below normal | [moderate confidence] |
| Barents Sea | below to near normal | [moderate confidence] |
| Sea of Okhotsk | below to near normal | [moderate confidence] |
| Labrador Sea | below to near normal | [low confidence] |

**Table 2:** Outlook for winter 2018-2019 Sea ice extent by region

# Planned upgrade to CIS seasonal outlook

## Existing Seasonal Outlook

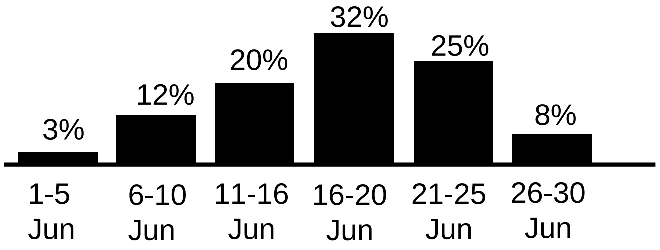


North American Arctic Waters
Summer 2014

**Table 2: Eastern Arctic - Outlook Dates**

| Arctic Events | Earliest Date (1968-2013) | Latest Date (1968-2013) | Median (1981-2010) | Outlook |
|---|---|---|---|---|
| **Baffin Bay Northern Route**<br>**- Open drift or less**<br>**- Bergy water** | 10 Jun<br>13 Jun | 18 Aug<br>15 Sep | 13 Jul<br>27 Jul | 5-7 Jul<br>19-21 Jul |
| **Baffin Bay Area**<br>**- Bergy water** | 10 Aug | 7 Oct | 6 Sep | 22-24 Aug |
| **Frobisher Bay to Home Bay Route**<br>**- Open drift or less** | 22 Jul | 19 Sep | 5 Aug | 30 Jul-1 Aug |
| **Frobisher Bay to Cape Dyer Route**<br>**- Open drift or less** | 24 Jun | 15 Sep | 25 Jul | 21-23 Jul |

- Envisaged advance is for these forecasts to become
  - model-based (direct or downscaled)
  - probabilistic →
  - accompanied by skill measure



- Content may change based on end user needs

# POLARIS/AIRRS indicators

- Navigation safety indicator based on ice conditions & ship class:

Risk Index Outcome

Concentration of ice type$_n$

$$RIO = C_1RV_1 + C_2RV_2 + \cdots + C_nRV_n$$

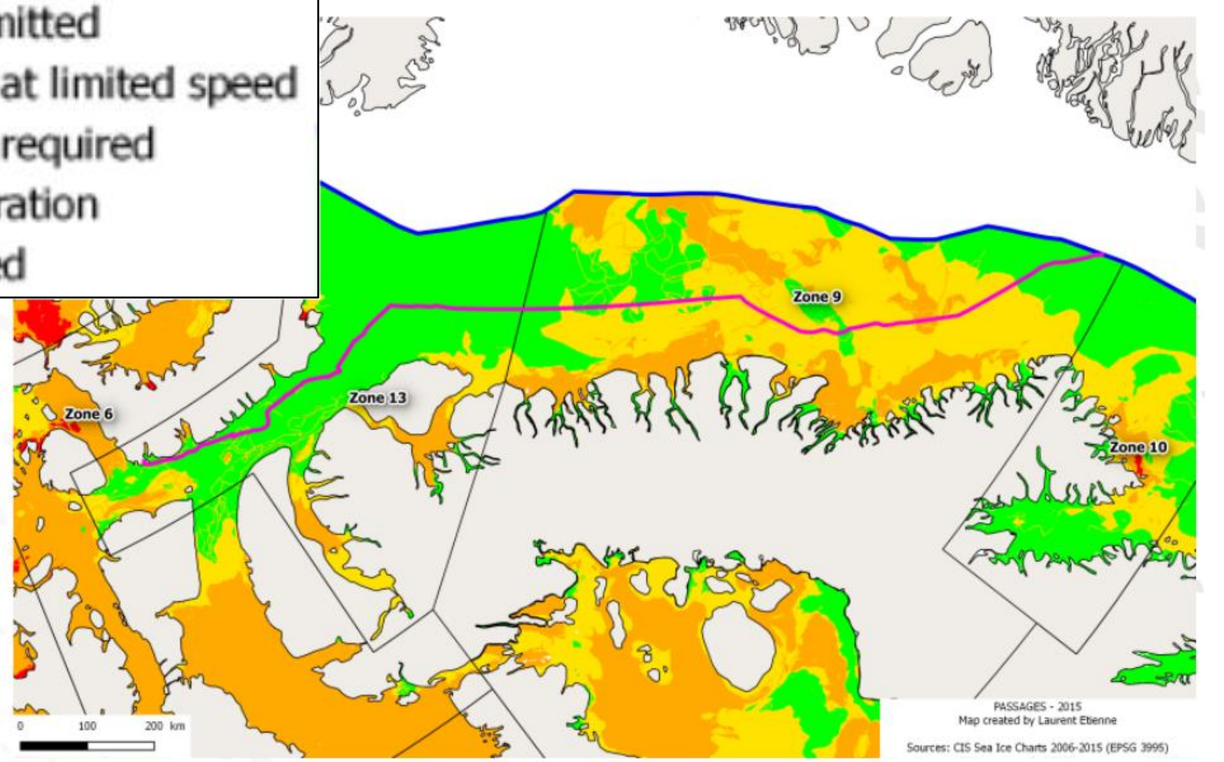
Risk Value$_n$

Ship track

**POLARIS RIO**

- 🟥 Operation not permitted
- 🟧 Ice breaker escort at limited speed
- 🟧 Ice breaker escort required
- 🟨 Limited speed operation
- 🟩 Operation permitted

**Median Polaris Index - IA vessel - Week 30**



Based on data from
digitized CIS charts →

***Stoddard_et_al. (2016)***

# POLARIS/AIRRS indicators

- ECMWF and FMI have been experimenting with POLARIS/RIO forecasting
- Ice types from regression on model variables

Extended-range sea ice forecasts for ship routing (ship class PC5)

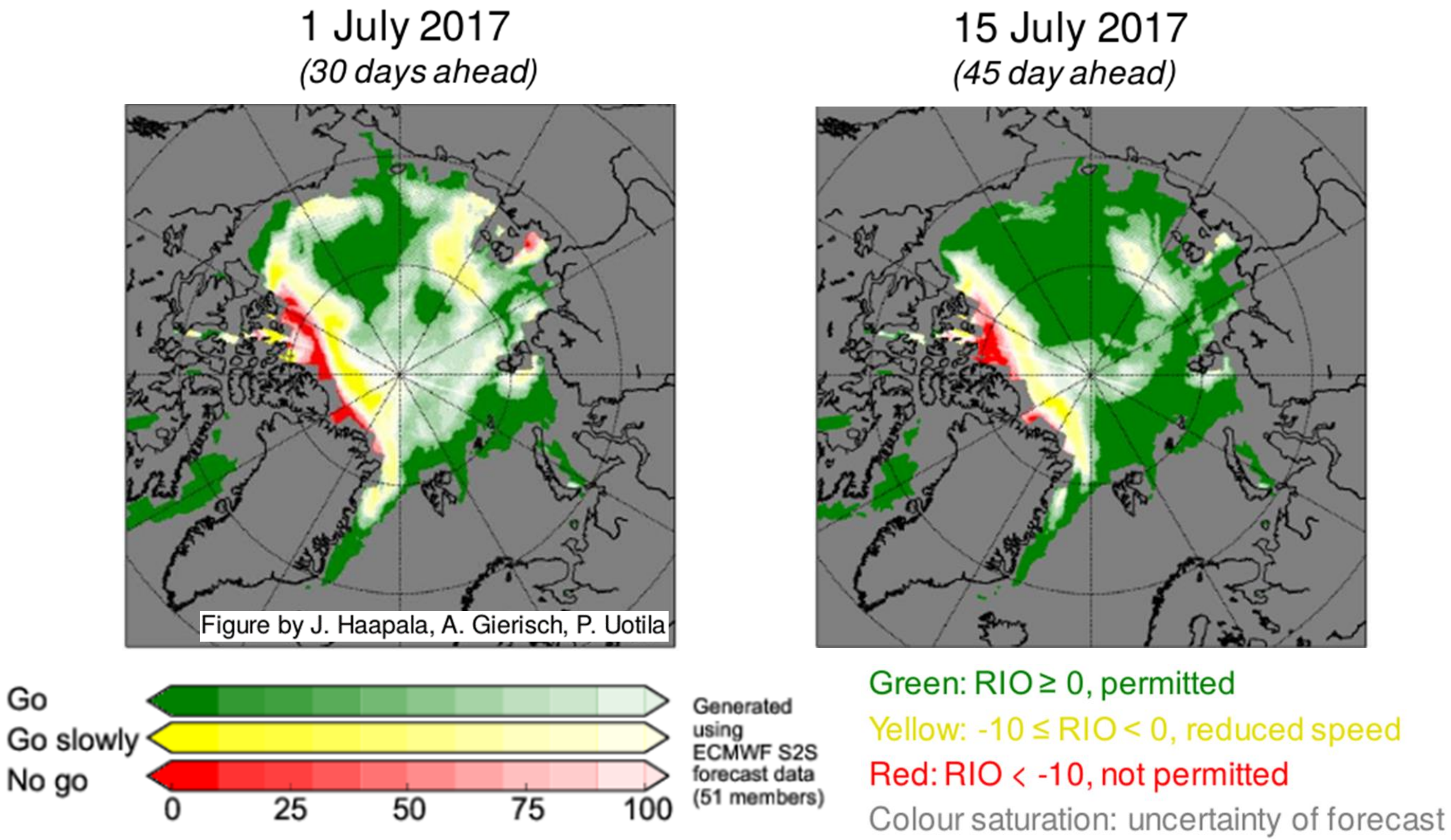


Figure by J. Haapala, A. Gierisch, P. Uotila

Generated using ECMWF S2S forecast data (51 members)

Green: RIO ≥ 0, permitted

Yellow: -10 ≤ RIO < 0, reduced speed

Red: RIO < -10, not permitted

Colour saturation: uncertainty of forecast

# POLARIS/AIRRS navigability indicators

- Jackie Dawson will be sharing ship track database, initially for Hudson Bay